IMPROVING FIRE STATION TURNOUT TIME THROUGH DISCRETE-EVENT SIMULATION

THESIS

Keegan D. Vaira, Captain, USAF

AFIT-ENV-MS-17-M-233

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENV-MS-17-M-233

IMPROVING FIRE STATION TURNOUT TIME THROUGH DISCRETE-EVENT SIMULATION

THESIS

Presented to the Faculty

Department of Systems Engineering and Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

Keegan D. Vaira, BS

Captain, USAF

March 2017

AFIT-ENV-MS-17-M-233

IMPROVING FIRE STATION TURNOUT TIME THROUGH DISCRETE-EVENT SIMULATION

Keegan D. Vaira, BS
Captain, USAF

Committee Membership:

Lt. Col. Gregory D. Hammond, PhD
Chair

Maj. Christina F. Rusnock, PhD
Member

Dr. Alfred E. Thal, Jr, PhD
Member

AFIT-ENV-MS-17-M-233

Abstract

The fire station is a critical aspect of the emergency response system, yet the role fire station design plays during an emergency response is rarely studied. This inattention results in decreased emergency response capabilities and diminishes the ability for first responders to provide essential aid. This research applies the facility layout problem through the use of discrete-event simulation to both improve existing fire stations and to find optimal designs for new fire station construction. The discrete-event simulation model describes the effectiveness of a fire station by measuring and predicting turnout time. For this research, turnout time consists of both dispatch by a controller in a 911 call center, and turnout, in which controllers notify the responders, who prepare for the emergency by donning their personal protective equipment and boarding their emergency vehicles. This research found a potential 28.85% reduction in turnout time for a case study fire station through facility layout improvement methods and provides a design tool that predicts fire station turnout time for facility layout construction methods. Applying this research could positively impact the nation's emergency response system and reduce the risk of losing life, limb, and property to communities served by improved fire stations.

To my wife for her never-ending love and support

Acknowledgments

There are many people I am greatly indebted to for their indispensable support during this research effort. I would first like to thank my thesis advisor, Lt Col Gregory Hammond, for his professional and personal assistance in every step of this research effort. His guidance and suggestions were vital to my success. Another big thank you goes to committee members Maj Christina Rusnock and Dr. Al Thal. Their knowledge and guidance helped forge a rough idea into a finished product. I am also grateful to the members of the Wright Patterson AFB Fire Department, Edwards AFB Fire Department, and West Metro, Denver Fire Department along with Chief Robert Olme for providing critical information and motivation for completing this research. Furthermore, I would like to thank Lt Col Rusty Vaira and Lt Col Brady Vaira for their interest in my professional and academic development and support they have shown me during my time at AFIT. Finally, I would like to express my deepest appreciation to my wife and children. I am so blessed to have such a wonderful family whose patience, support, and encouragement were essential throughout this endeavor.

Keegan D. Vaira

Table of Contents

Page

Page

List of Figures

Page

Page

List of Tables

Page

Page

IMPROVING FIRE STATION TURNOUT TIME THROUGH DISCRETE-EVENT SIMULATION

1. Introduction

A first responder's emergency response capability is vitally important to provide life, limb, and property saving aid, but these responders often cannot egress a fire station quickly enough. Many factors affect the ability of first responders to be able to quickly egress a fire station, yet no method currently exists to determine those factors or measure the extent to which the design of the fire station affects that emergency response capability. The use of discrete-event simulation offers a solution to improve the operational effectiveness of a fire station by highlighting improvement areas for existing fire stations and by providing a design tool that predicts the fire station's response capability before construction.

1.1 General Background

For emergency responders, every moment is critical as they attempt to prevent negative outcomes. Mattsson and Juas (1997) found that responses delayed by as little as five minutes can cause overall damage to increase by 97 percent for tightly coupled events such as structural fires, road accidents, or drowning cases. This delta of five minutes is even more critical for events such as aircraft ground emergencies or life-threatening health emergencies. Aircraft fires have an extremely short response time; in commercial passenger aviation, it is widely known that passengers have less than 60 seconds to evacuate a plane before the probability of serious injury or death dramatically increases (Ripley, 2009). Similarly, the arrival of emergency responders in five minutes instead of seven can nearly double the probability of survival in heart attack victims (Pell, Sirel, Marsden, Ford, & Cobbe, 2001). Emergency response professionals know the importance of a timely response and must be able to arrive on-scene quickly. The timely response begins at the fire station, and the building's architectural layout either supports or hinders the response effort.

Fire and emergency services governing bodies developed emergency response guidelines based on research conducted by the International Association of Fire Chiefs Accreditation Committee (IAFCAC) and disseminated these critical time recommendations through all levels of the fire service industry. The National Fire Protection Agency (NFPA) 1710 is the governing document, and additional guidance is mirrored throughout different governing documents at the national, regional, and local levels (Stauber, 2003). The IAFCAC research showed that to deliver the most effective service, one-minute for dispatch, one-minute for firefighter egress from the station, and five minutes to travel to the scene of an incident or less are critical time checkpoints. The one-minute dispatch time and one-minute firefighter egress time collectively are termed "turnout time." Current regulations do not enforce these guidelines, and only personal and societal pressures at local districts provide an incentive to meet this performance goal.

Many stations and departments have difficulties achieving their response goals ("NFPA," 2016). A 2012 study of 15 fire departments who collectively answered just over 183,000 response calls showed the mean response time for phase two of turnout (i.e., notification by dispatchers, donning of personal protective equipment, and vehicle boarding) time alone to be 116 seconds—well above the 60-second benchmark set by the

NFPA (Haden, 2016). Air Force fire departments are no exception to the difficulties in meeting the desired turnout times. A 2015 study found the turnout times for a sample Air Force fire department were met only 47% of the time for EMS, HAZMAT, and fire responses (Greszler, Gallucci, & Sundheim, 2015). With well over 200 million emergency dispatch calls occurring in the United States (*National 911 Program*, 2013), and that number increasing each year, the need for an improved response capability exists to enable emergency responders the best chance at saving life, limb, and property for the communities they serve. Efforts have been made to streamline the turnout time process since the inception of NFPA guidelines, but they have achieved limited success.

Previous research has examined the issue of turnout time enhancement. The National Fire Protection Agency continuously attempts to increase the effectiveness of fire departments nationwide. Stauber (2003) and Weninger (2004) examined the issue of turnout times in an applied research project submitted to the National Fire Academy as part of an Executive Fire Officer program. The research conducted by these two fire chiefs sheds light on the importance of this topic to first responders. However, both papers also indicate a need to further research turnout time to provide responders with additional tools to help save lives.

Stauber's research centered on which standards and regulations exist regarding fire department response time, how those standards are determined, and which factors affect the duration of turnout time (Stauber, 2003). He used a Time-Motion Study to collect data showing average times of several factors including how long it takes to don different types of equipment, travel times from particular rooms, and effectiveness of certain equipment items such as radios. The recommendations based on his research included collecting and analyzing additional data to more effectively schedule personnel and resources to adequately meet the demand of increased activity periods, upgrading the data collection software to better track turnout time data, implementing a radio emergency incident alert system, and decreasing the initial dispatch message to contain essential information only.

Weninger's research aimed to discover what components and tasks contribute to overall turnout time, and what changes should be made to reduce that time (Weninger, 2004). He used surveys to elicit responses from experienced station leaders with a rank of captain and above. The conclusions from his research included the need to clearly define the expectation of meeting the turnout time to all responders, implementing accountability measures by including turnout time metrics in performance appraisals, parking high-use apparatus close to the responders' pathway entrance, and creating an environment of competition by awarding fast turnout times through positive performance evaluations.

1.2 Specific Background

The facility layout problem, which seeks to optimize a facility layout for a given function, offers a method to improve first responder speed from a fire station. It is instrumental to system productivity and efficiency and offers a means to improve a facility with key goals in mind (Kusiak & Heragu, 1987). It does this through two main ways, improvement methods and construction methods. Construction methods focus on improving a facility's design before it is constructed, while improvement methods focus on making changes to improve an existing facility (Glenn & Vergara, 2016).

A myriad of techniques including discrete formulation, continual formulation, fuzzy formulation, multi-objective layout, and exact or approximate resolution approaches have emerged to solve facility layout problems depending upon the specific physical characteristics of the facility such as size and shape, the overall objectives of the facility, and the analytical approaches and specific method desired by the problem solver (Drira, Pierreval, & Hajri-Gabouj, 2007). At its core though, facility layout problems determine ways to quantify, evaluate, and compare different layouts through the use of performance measures.

Simulation is often a fundamental part of layout planning and offers the only methodology robust enough to examine the role and impact of the facility design and capture the real-life issues that are often overlooked while using mathematical algorithms (Burgess, Morgan, & Vollmann, 1993; Gan, Richter, Shi, & Winter, 2016). Furthermore, it has been used before in both construction facility layout problems as well as improvement facility layout problems. Greasley (2008) showed that discrete-event simulation worked well for construction applications when he used it to determine the best design for a textile mill. Multiple health care system studies show discrete-event simulation to be effective in improvement facility layout problems (Duguay & Chetouane, 2007; Günal & Pidd, 2010; Jacobson, Hall, & Swisher, 2013; Jun, Jacobson, & Swisher, 1999; Komashie & Mousavi, 2005).

The use of discrete-event simulation worked well for the previous studies because the key processes of the facility could be categorized as discrete, dynamic, and stochastic. The key processes inherent in fire stations can also be described in this way. For this research, discrete-event simulation was used to determine key factors and improvement areas of a fire station, as well as to provide a design tool to predict a fire station's aptitude to aid first responders during an emergency response.

1.3 Problem Statement

There is currently no method available to measure or evaluate the effectiveness of fire station facility design based solely on the architectural layout. With the high importance of emergency response, a way to both predict fire station response capability before construction and implement corrective measures for existing stations is paramount.

1.4 Research and Investigative Questions

The purpose of this research is to understand how the operational effectiveness of fire stations can be improved by applying facility layout simulation methods. The motivation is to use this framework to reduce turnout times at fire stations. This research begins with a case study involving a single fire station to apply the improvement method (or making changes to an existing facilities layout or operational process to improve operational effectiveness) of the facility layout problem. It uses the station to understand how risk assessment and simulation can be used to reduce turnout times by creating a model. The simulation model is then validated and tested using additional stations for application in the construction method (finding the facility layout that most aids the operational process during the design phase of construction to optimize operational effectiveness) of the facility layout problem. The research objective will be achieved by answering four investigative questions.

1. What are the key Configurable, Environmental, Procedural, and Behavioral risk factors that affect turnout time at the case study fire station?
2. What changes can be implemented at the case study fire station to reduce turnout time and what are the predicted impacts of the changes?
3. How effective is the case study simulation model at predicting fire station turnout time for other fire stations based upon facility layout?
4. How can the simulation model be used to evaluate proposed fire station designs?

1.5 Methodology

The research question was answered using a discrete-event model that was created using Rockwell's ARENA software. Input parameters for the model were collected via a time and motion study and expert opinion. After the baseline model was built, it was modified to represent the case study fire station with targeted changes implemented to remedy identified risk factors. The baseline model was also modified to act as a design and decision aid for new fire stations. Statistical analysis was used to validate all baseline models and simulation was used to predict turnout time.

1.6 Thesis Organization

The thesis follows a scholarly article format. Chapter 2 is an article that focuses on improvement methods and has been accepted to the Industrial and Systems Engineering Research Conference. It uses Failure Mode and Effects Analysis (FMEA) to identify the factors that affect turnout by considering configurable, procedural, environmental, and behavioral characteristics at the case study fire station. The article provides a simulation model of fire station turnout time.

The second article, found in Chapter 3, applies construction methods. It details the aptitude for the model built for the case study fire station to be used across other fire stations and its efficacy to predict turnout time based upon design alone and the capabilities it offers to future design efforts. This article has been prepared for submission to the Journal of Simulation Modeling and Practice. Statistical comparisons of multiple fire stations across the country were completed by testing turnout time data and station designs to determine if the model could be generalizable. Additionally, a successful generalization of this model leads to the fourth research question. The use of a turnout time predictive model based on the design of a fire station alone will help architect and engineering firms, as well as decision-makers, choose fire station designs that increase the emergency response capability to its fullest potential.

Each article includes a literature review, methodology, results, and conclusion section about each topic is discussed. Following the articles, the thesis ends with a conclusion, Chapter 4, which summarizes the research and its findings as well as offers potential follow-on research topics. Appendix A offers an extended literature review covering topics discussed in both articles. It covers operational effectiveness of fire stations, an in-depth look at fire station risk factors, and showcases the use of simulation as a tool. The remaining appendices offer additional information relevant to the methodology and results not included in the article submissions and presents the data collection tables used to build and validate the simulation model.

2. Improving Fire Station Turnout Time: *Conference Proceedings to the Industrial and Systems Engineering Research Conference*

Abstract

Fire station turnout time is vitally important to firefighters' ability to provide lifesaving services. Turnout time consists of two phases: first, dispatch by a controller in a 911 call center; and second, turnout, in which controllers notify the responders, who prepare for the emergency by donning their personal protective equipment and boarding their emergency vehicle. The National Fire Protection Agency (NFPA) recommends a two-minute turnout time, yet fire stations do not always meet this guideline. Efforts have been made to streamline the turnout time process since the inception of the guidelines, with limited success. Exploring potential options can be risky and costly to implement; simulation provides a means of overcoming these obstacles. This case study considered configuration, procedural, and behavioral factors at a single fire station with discrete-event simulation to identify possible remedies. This study aims to provide fire stations a framework for design to increase the lifesaving potential offered to their community by decreasing turnout time. At the fire station studied, implementing a procedural and behavioral change that provided early responder notification of an emergency decreased the simulated turnout time by 24.3%. Similar results may exist at many fire stations allowing for a raised lifesaving service and NFPA adherence.

2.1 Introduction

For emergency responders, every moment is critical as they attempt to prevent negative outcomes. Mattsson and Juas (1997) found that responses delayed by as little as five minutes can allow overall damage to increase by 97-percent for tightly coupled events such as structural fires, road accidents, or drowning cases. Similarly, the arrival of emergency responders in five minutes instead of seven can nearly double the probability of survival in heart attack victims (Pell et al., 2001). Fire and emergency services governing bodies know the importance of a timely response and have developed emergency response guidelines based on research conducted by the International Association of Fire Chiefs Accreditation Committee. The research showed that to deliver the most effective service, turnout from the station needs to be two-minutes or less and travel to the scene of an incident five minutes or less. Fire stations measure turnout time in two different phases: first, dispatch by a controller in a 911 call center; and second, turnout, in which controllers notify the responders, who prepare for the emergency by donning their personal protective equipment and boarding their emergency vehicles.

The purpose of this research is to understand how the operational effectiveness of the case study fire station can be improved by applying applicable configurable, procedural, and behavioral factors. The motivation is to use this framework to reduce turnout times at fire stations. This research begins with a case study involving a single fire station located at Wright-Patterson Air Force Base. It uses the station to understand how risk factors and simulation can be used to reduce turnout times through the creation of a model. The research objective is achieved by answering two investigative questions:

1. What are the key configurable, procedural, and behavioral risk factors that affect turnout time at the case study fire station?
2. What changes can be implemented at the case study fire station to reduce turnout time and what are the simulated impacts of the changes?

2.2 Literature Review

Emergency response is a fundamental government service. Safe municipalities depend on emergency services. To effectively respond to a crisis, a system of plans, authorities, policies, procedures, personnel, training, materials, equipment, and facilities must function together towards a common goal (Jackson, Sullivan Faith, & Willis, 2011). How to successfully combine these elements to work together efficiently, consistently, and dependably has been the goal of emergency research since its inception. Emergency management research is typically focused on improving the reliability of emergency management and response capabilities (Abrahamsson, Hassel, & Tehler, 2010; Ball & Lin, 1993; Henstra, 2010; Jackson, Faith, & Willis, 2010), yet, limited literature exists on the impact configurable, procedural, and behavioral factors may have on the system.

2.2.1 Operational Effectiveness

For this research, operation effectiveness is defined as any practice that allows a fire station to maximize its ability to meet all regulations and societal expectations as well as maximize its ability to provide emergency aid to the community it serves. The NFPA require first responders be timely in their response to an emergency call. The NFPA defines Total Response Time as the time interval from the receipt of the alarm at the primary station of responsibility to when the first emergency response personnel begin initiating an action or intervening to control the incident. To be accredited, all fire stations must measure the Total Response Time and meet a minimum level of service ("NFPA," 2016). For nearly every emergency type, the Total Response Time for the first arriving company is set to seven minutes. NFPA 1710 more specifically details the goals for each of the parts of Total Response Time: two minutes for turnout, and five minutes for travel. This shows that nearly one-third of the time is spent conducting turnout procedures. To that end, the need to look at configurable, procedural, and behavioral factors exists.

2.2.2 Configurable, Procedural, and Behavioral Factors

Configurable aspects concerning turnout time include well-established requirements such as those contained in the International Building Code and NFPA documents that dictate details such as number of exits, exit widths, and health requirements (Mesagna & Raroni, 1991; "NFPA," 2016, "Unified Facilities Criteria 4-730-10 Fire Stations," 2006). Many other aspects are not cemented in code, and consist of design freedoms such as the buildings layout, travel distance between rooms, the proximity between facility functions, and how many corners must be navigated to exit a building. Proulx (2001) found several building characteristics important for design professionals to consider when determining the egress capability of personnel during evacuations. These characteristics included building type, architectural details, facility function, and evacuation controls within the facility. These characteristics can be applied to fire station turnout because firefighters, when responding to an emergency, are essentially trying to egress or evacuate their fire station as quickly as possible. The characteristics applicable to fire station egress include the number of floors, floor area, the location of exits, the location of stairwells, the complexity of the space and wayfinding, the building shape, and visual access to exits.

Procedural considerations that may potentially influence turnout time include training levels, prior knowledge of the facility, the efficiency of donning safety equipment, and safety rules (Gwynne, Galea, Owen, Lawrence, & Filippidis, 1999) such as disallowing running in facilities. An individual's experience with any given task has a positive relationship with performance (Quińones, Ford, & Teachout, 1995). Experience is often attributed to more senior employees, but it is important to note that a mixed workforce of all experience levels has been shown to garner the best performance for an organization (Grund & Westergård-Nielsen, 2008). Continued training will build confidence and the ability for firefighters to respond to an emergency as efficiently as procedural requirements allow. Some requirements do slow down process completion though. Sometimes these requirements are wastes in the system, and sometimes they are added risk reduction steps. Safety procedures are one of the risk-reduction steps. While extremely important, they can inhibit job performance speed but increase worker happiness and satisfaction (Sackett, 2002). A workforce safety study found that 41% of workers overlook safety procedures to perform jobs faster (Hayes, Perander, Smecko, & Trask, 1998). Ignoring safety procedures is a counterproductive work behavior and can be more detrimental to an organization if left unchecked despite the potential speed advantage.

Behavioral concerns that may play a role in turnout time include the rate of travel speeds, reaction time to an alert, the emotional state of firefighters, and organizational decisions and norms. The rate of travel for firefighters moving from their in-garrison position to an emergency vehicle during an alarm scenario can influence the speed at which the first response team can provide their services. Walking speeds vary depending on age, sex, body composition, and physical ability (Himann, Cunningham, Rechnitzer, & Paterson, 1988). In the U.S. 75% of firefighters are between the age of 20 and 50 and almost predominantly male ("NFPA," 2016). Bohannon shows the mean comfortable gait speed for males between the age of 20 and 50 is 4.6 ft/s and the mean maximum walking speed for the same age group to be 8.2 ft/s (Bohannon, 1997). These values will act as the travel speed distribution parameters used to determine the time needed to travel a certain distance within the model. Research has found that humans normally do not elicit an immediate response to an alarm and spend time conducting pre-movement actions (Canter, Breaux, & Sime, 1980; Sime, 1985). Proulx (1994) discovered that this delay was not minimal and ranged greatly depending upon the type of alarm and risk associated with that alarm. His study has shown that even for well-trained individuals, it takes 15 seconds to begin actions associated with an alarm regardless of the alarm type.

These three categories take into account the physical characteristics of the building, the individual agent interactions that occur between stimuli within the station's environment, and the choices a person must make in response to those stimuli. Fully analyzing the configurable, procedural, and behavioral risk characteristics affecting fire station turnout time along with simulation modeling to test solutions could potentially lead to a decrease in both the variance and time for fire station turnout.

2.2.3 Simulation as a Tool

Discrete-event simulation models can describe the behavior of a system through a series of events that consists of a number of entities such as people or products with associated attributes such as time in the system, resource consumption, or cost at each process step. Furthermore, it provides a method for assessing how well the system process estimates approximate true, but unknown, system behavior (Fishman, 2013). A discrete-event simulation model assumes the system being simulated only changes state at discrete points in simulated time and allows all activities within a process to be compared to the end goal of the system such as reducing time or cost (Fujimoto, 1990). Discrete-event simulation has become a popular and effective decision-making tool for the optimal allocation of limited resources and spaces to improve process flow and process cost (Jacobson et al., 2013). Similarly, reliability analysis is concerned with determining a system's overall failure potential based on the failure probabilities of the components of the system (Robert E. Melchers, 1999). In time-dependent system reliability analysis, discrete-event simulation methods have been used to determine the distributions of time likely for a system to reach completion based upon the individual time distributions for the completion of sub-steps.

Simulation enables researchers to conduct repeatable, experimental trials for events that occur rarely or within systems that, even under the most controlled conditions, produce varied results. Simulation also gives engineers a means to test building designs without full-scale demonstrations to show the effects different proposals may have in regards to adherence to prescriptive building codes and the rigid regulations held within them. Furthermore, simulation offers a structured avenue to test potential solutions where actual implementation is costly or difficult.

2.3 Methodology

The steps outlined in this section describe the methodology followed when evaluating the investigative questions. An action research based approach was taken to both provide an example of practices used to conduct this research and to test if the discrete-event simulation approach is a useful tool in the context of facility design. Furthermore, this approach was used to discover if turnout time process improvement suggestions based on key factors is feasible. The authors of this research acted in an observatory role and carried out both the process of the study and constructed the discrete-event simulation model. The author completed collection of data to include process durations, task allocations, and process relationships for the study by observing and interviewing employees of the case study fire station in order to construct the simulation model used in the analysis. The model's intent is to mirror the turnout time processes of the case study fire station to determine the processes most detrimental to dispatch and firefighter egress guidelines. The model does this by breaking the processes into several distinct steps and covers scenarios the firefighters may face when egressing from the station.

A time-and-motion study was conducted at the sample fire station. Task times of the activities were fit to probability distributions and incorporated into a baseline simulation model created with Rockwell's ARENA software. The baseline model was then validated by comparing simulated response times to historical data. After validation, alternative models with specific system modifications were built incorporating procedural, behavioral, and configuration changes to the system. Each model was run for

300 replications to evaluate the fire station's likelihood of meeting the two-minute guideline.

2.3.1 System Description and Assumptions

The first step in the methodology is to represent the turnout time events taking place at the case study fire stations as discrete steps. Natural breaks presented themselves in the process making partitioning of the timed events easy to discern. Eight key steps (Figure 1) were found to describe the flow of events currently completed by firefighters to dispatch and egress the case study fire station. In order, those steps were: (1) Phone Rings In Dispatch Center And Dispatcher answers the phone, (2) dispatcher initiates call over intercom, (3) firefighters stop current activity, (4) firefighters travel to fire engine in station bay, (5) firefighters open garage door, (6) firefighters don equipment, (7) firefighters conduct pre-movement protocol, (8) fire engine departs station. Additionally, four assumptions were made: (1) only one response can be run at a single time, and simultaneous responses will not occur, (2) subject matter expert inputs are correct, (3) flow of processes conducted will not change, and (4) there will be no failures in the system.

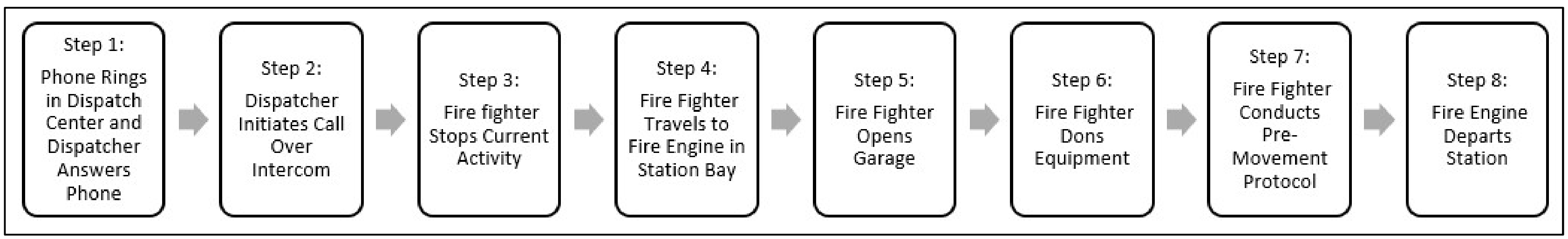


Figure 1: Eight Key Steps in Firefighter Turnout

2.3.2 Task Network and Description

The model begins when the emergency response phone rings in the dispatch center. The first process immediately follows this and measures the time it takes a dispatcher to answer the phone, communicate with the caller, and collect and record all information pertinent to the emergency. Detailed records of this step exist and show that these calls last anywhere from 10 to 65 seconds with the mean at 25 seconds. The model then measures the time it takes for the dispatcher to relay the emergency message to the fire station. This follows a normal distribution and lasts anywhere from 5 to 15 seconds. After these steps, the model transitions from the dispatch portion of turnout time and focuses on the egress portion. The models next step is to pre-determine if the garage door the firefighters will leave from is open or not. Subject matter expert interviews show that 35% of all calls will have the door previously open. The model assigns the door as open or as closed and if open, assigns the firefighters to a door open egress procedure that skips opening the garage door. Next, the model determines the emergency call type. Numerous and detailed data exist and show the likelihood a call will be either medical, structural, or other. After the call type is determined, the model randomly dedicates firefighters to certain jobs. Each of these simulated firefighters will then act independently of the next throughout the remainder of the model and will not act as a single unit again until all firefighters are in the fire engine and departing the station. After separating firefighters by call type, each firefighter is then assigned to be in one of eight possible locations within the fire station. Those rooms are the dorms, kitchen, restroom/shower, recreation room, gym, training room, garage bay, or an administrative office. The decision of what room each firefighter is in is based upon room occupancy rates gathered from subject matter expert interviews and author observation. Each room has an associated pre-movement time that includes the time to turn off cooking appliances, finish in the restroom, log-off a computer, and many other activities the firefighters must finish before exiting the room. Each room will also have an associated travel time from that room to the fire engine. These times are calculated using the walking speeds of an athletic adult and distances from the room to the fire apparatus. If the garage door is closed, the firefighter will open the garage door and then proceed to don protective equipment. If the garage door is open, the firefighter will proceed immediately to donning protective equipment. The last step is to depart the fire station. This cannot occur until all firefighters have completed each prior procedure assigned.

This model is designed to run each call independently of the next. When the model was run for 300 replications, the fastest turnout time was 1.35 minutes, the slowest was 3.06 minutes, and the average was 2.31 minutes. The processes with the most influence on turnout time were donning equipment, answering and collecting information from the emergency call, opening the garage, and travel time to the garage bay. This information was used to determine process improvements to improve response time. Overall, this model mimics the turnout time activities of the case study fire station and is useful in determining what factors contribute most to the overall dispatch and egress times.

2.3.3 Validation

Baseline model validation was conducted using a Student's t-test. The baseline simulation data were compared to five years of data (N=482) collected by the case study fire station for the actual time it took the fire station to complete the phases of turnout.

The results of the test, *t(299)=2.33, p=0.59,* support the finding that the baseline model and reality are statistically equivalent. Running the simulations in ARENA identified the critical nodes within the system. These critical nodes were used to create alternative models. Appendix B offers additional information relevant to this section.

2.3.4 Experimental Design and Alternative Model Description

Alternative Model #1: The first alternative model implements a procedural change giving the ability for the dispatcher to open the garage door via the dispatch center when the call first comes in. This eliminated the need for the first firefighter to spend time opening the garage and vastly reduced the likelihood that the garage door was the factor inhibiting the fire truck from leaving the station.

Alternative Model #2: The second alternative model implemented a procedural and behavioral change giving the dispatch center the ability to pre-warn firefighters of an impending call. This occurred by giving the dispatcher the ability to alert firefighters before completing the emergency call. The information the dispatcher collects is transmitted via the intercom system or radios once the dispatcher has ended the call. This gave the firefighters a head start on their egress procedures allowing for a faster turnout time but required a different response mindset by requiring firefighters to begin turnout with limited information.

Alternative Model #3: The third alternative model implemented a configurable change and included changing the layout of the station allowing the rooms with the highest occupancy rate to be closer to the bay than rooms with a lower occupancy rate.

This allowed for the travel time between rooms and the bay to be as low as possible given the same building shape.

2.4 Results

Each alternative model individually and in combination was simulated through ARENA. The results yielded the following turnout time percent reductions from the baseline model (M=2.31, SD=0.86):

(1) All Changes-28.85% (M=1.64, SD=0.59),

(2) Alternative Model #1-3.00% (M=2.24, SD=0.91),

(3) Alternative Model #2-24.26% (M=1.75, SD=.68),

(4) Alternative Model #3- 1.15% (M=2.28, SD=.59),

(5) both Alternative Model #2 & #3-27.54% (M=1.67, SD=0.84).

Using confidence intervals with an alpha of 0.95 between the baseline and alternate models showed that Alternative Model #1 and Alternative Model #3 alone are not statistically different from the baseline model. Alternative Model #2 (Figure 2), the combination of both Alternative Model #2 and #3, and All Changes are statistically different from the baseline model and are the only models that should be taken into consideration when deciding upon a solution to implement.

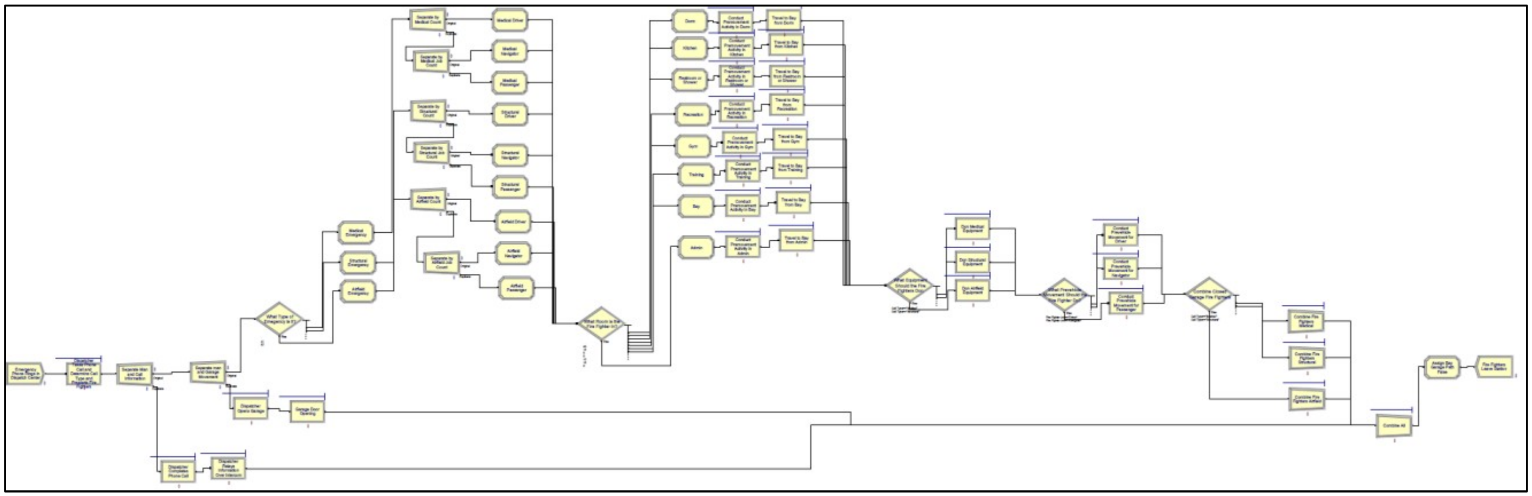


Figure 2: ARENA Alternative Model #2

2.5 Conclusion and Recommendations

The results showed that the factors most affecting turnout time at the case study fire station were procedural and behavioral. As such, these factors should be looked at in more detail in future research. Specific to the case study fire station, the author recommends implementing Alternative Model #2. Doing so will decrease turnout time the most without requiring a lengthy and costly remodel or additional equipment. Implementing this procedural and behavioral change could reduce turnout time at the case study fire station by 24.26% and allow the fire station to more reliably meet NFPA guidelines and provide emergency services to the community.

3. Improving Fire Station Turnout Time: Pending Submission to the *Journal of Simulation Modeling and Practice*

Abstract

The fire station is a critical aspect of the emergency response system, yet the role fire station design plays during an emergency response is rarely studied. This inattention results in decreased emergency response capabilities and diminishes the ability for first responders to provide essential aid. This research applies the facility layout problem through the use of discrete-event simulation to predict the turnout time of fire stations prior to construction. The model was found to be adept at determining a fire station's turnout time. It was also found that the process of applying the methodologies associated with this research could initiate useful discussion regarding the operation effectiveness of many facility types. Applying this research could positively impact the nation's emergency response system and reduce the risk of losing life, limb, and property to communities served by improved fire stations.

3.1 Introduction

For emergency responders, every moment is critical as they attempt to prevent negative outcomes. Mattsson and Juas (1997) found that responses delayed by as little as five minutes can cause overall damage to increase by 97 percent for tightly coupled events such as structural fires, road accidents, or drowning cases. This delta of five minutes is even more conservative than is desired within other events such as aircraft ground emergencies or life-threatening health emergencies. Aircraft fires have an extremely short response time; in commercial passenger aviation, it is widely known that passengers have less than 60 seconds to evacuate a plane before the probability of serious injury or death dramatically increases (Ripley, 2009). Similarly, the arrival of emergency responders in five minutes instead of seven can nearly double the probability of survival in heart attack victims (Pell et al., 2001). Emergency response professionals know the importance of a timely response and must be able to arrive on-scene quickly. A timely response begins at the fire station, and the fire station's layout either supports or hinders the response effort.

The facility layout problem, through the use of simulation methods, offers a method to improve first responder speed from a fire station during emergency situations. Solutions to the problem are categorized into construction and improvement methods. Construction methods focus on improving a facility's design before its construction, while improvement methods focus on making changes to improve an existing facility (Glenn & Vergara, 2016). This research applied construction methods through a simulation-based approach to help fire station designs support the timely response of first responders.

The purpose of this research is to understand how the operational effectiveness of fire stations can be measured and improved by applying simulation methods to the facility layout problem during fire station design. For this research, operational effectiveness was defined as any practice that allows a fire station to maximize its ability to meet regulations, societal expectations, and provide emergency aid to the community it serves. The research contributes to the literature by providing a methodology to determine the turnout time capability analytically (i.e. time needed for firefighters to prepare and egress a fire station for an emergency response) of proposed fire station designs. A discrete-event simulation model was built based upon the case study of a single fire station. The model was then evaluated against nine additional fire stations to determine its effectiveness as a design tool.

3.2 Literature Review

Previous research is limited with regards to the issue of turnout time enhancement. Existing case studies and publications that have studied this issue focus mostly on process improvement aspects of turnout time. Stauber (2003) and Weninger (2004) both examined the issue of turnout times in applied research projects for the National Fire Academy. Stauber's research centered on existing standards and regulations regarding fire department response time, how those standards are determined, and which factors affect the duration of turnout time (Stauber, 2003) while Weninger's research investigated components and tasks that contribute to overall turnout time, as well as changes to reduce that time (Weninger, 2004).

3.2.1 Facility Layout Problem

Facility layout is instrumental to system productivity and efficiency (Kusiak & Heragu, 1987). The facility layout problem offers a means to improve a facility with key goals in mind by attempting to optimize the location of equipment and its functions. In general, literature about the facility layout problem revolves around production facilities focusing on the improvement of manufacturing costs, work in process, lead times, and productivity (Drira et al., 2007; Kusiak & Heragu, 1987; Meller & Gau, 1996; Yaman & Balibek, 1999). Yaman and Balibek (1999) describe it as an unstructured decision problem that may have several sub-decisions associated with it that all require different solution methods. A myriad of techniques including discrete formulation, continual formulation, fuzzy formulation, multi-objective layout, and exact or approximate resolution approaches have emerged to optimize facility layout problems depending upon the specific facility's physical characteristics such as size and shape, the facility's overall objectives, and the analytical approaches desired by the problem solver (Drira et al., 2007). At its core though, facility layout problems determine ways to quantify, evaluate, and compare different layouts through the use of performance measures related to a facility's goal. These problems are often complex and do not have an optimal solution, but rather several good solutions that a decision-maker must choose from. While facility layout problems focus mainly on production and manufacturing facilities, Glenn and Vergara (2016) showed facility layout problem principles could be more diverse when they used it to develop optimal equine facility layouts. Within non-production affiliated facilities, capturing various building and process characteristics in search of the optimal layout is often difficult and uneconomical (Drira et al., 2007). To combat this issue, simulation has become a common theme throughout facility layout problems to account for the uncertainty of building and process characteristics. It also provides a tool to both measure the effectiveness of designs and to aid in process improvement efforts within pre-established and alternative layouts meeting the desired user constraints (Liggett, 2000).

3.2.2 Discrete-event Simulation as it Applies to Facility Layout Problem

Many facility layout problem methods exist, yet none were found that were directly applied to fire stations. Due to the unique function of a fire station and the need to predict the operational effectiveness of a fire station design, the use of simulation was deemed to be the most appropriate method to evaluate the facility layout problem. Simulation is often a fundamental part of layout planning and offers a methodology robust enough to examine the role and impact of the facility design and capture the real-life issues that are often overlooked while using mathematical algorithms (Burgess et al., 1993; Gan et al., 2016). Simulation is often used to estimate system parameters by contrasting different layout configurations in terms of operational parameters and identifying potential problems and bottlenecks in proposed layouts (Iannone, Miranda, Prisco, Riemma, & Sarno, 2016; Ramirez-Valdivia, Christian, Govande, & Zimmers, 2000).

There are two main contrasting viewpoints on how simulation can be used in facility layout problems (Aleisa & Lin, 2005). The first technique is to develop a layout and then use simulation to judge its merit; the second technique is to optimize a process through simulation and then develop a layout that is compatible with the process. For facilities with system processes characterized as irregular or always changing, simulation and then layout is often recommended because it allows for the estimation of flow and accounts for the uncertainty in a forecasted goal. In contrast, facilities displaying predictable behavior with predetermined goals can elicit better gains by using layout and then simulation (Aleisa & Lin, 2005). The nature of fire stations fits well into the "layout then simulate" technique because response goals are often predetermined. Greasley (2008) showed that discrete-event simulation is an appropriate simulation method to use in the context of "layout then simulate" and will be the simulation method used in this research.

The discrete-event simulation method is effective at solving the facility layout problem because it gives the ability to describe the uncertainty of the behavior of a system and includes the event, attribute, and entity characteristics for each step. Furthermore, it provides a method for assessing how well the system process estimates approximate true, but unknown, system behavior (Fishman, 2013; Furian, O'Sullivan, Walker, Vössner, & Neubacher, 2015). A discrete-event simulation model assumes the system being simulated only changes state at discrete points in simulated time and allows all activities within a process to be compared to the end-goal of the system such as reducing time or cost (Fujimoto, 1990). This is especially useful when determining the effectiveness of a design. Including layout or process dependent attributes such as travel distance or time between process steps, or the allowable resource allocation at each step of a proposed design, will show the predicted system behavior for the system's end-goal.

3.3 The Facility Layout Problem Fire Station Case Study

To measure the operational effectiveness of a fire station's turnout process, a discrete-event simulation model was created. The first step to creating the model was to conduct a Time-Motion Study at a sample fire station. The time and motion study determined the main stages of the turnout process and task times of the activities involved. This data were collected by observing and interviewing employees of the case study fire station and collecting process duration, task allocation, and process relationship data. Rockwell's ARENA software was then used to incorporate the results into a baseline simulation model using triangular probability distributions. The model's intent is to mirror the turnout time process that covers scenarios responders face when egressing from a fire station.

To construct the discrete-event simulation model, the observed turnout time process was decomposed into discrete steps. Natural breaks presented themselves in the process, thereby making partitioning of the timed events easy to discern. As shown in Figure 3, the steps currently completed by firefighters to egress a fire station are: (0) dispatch, or system set-up, (1) firefighters stop current activity when notified by dispatch center and conduct pre-movement activities, (2) firefighters travel to the fire engine in the station bay, (3) firefighters don equipment, and (4) firefighters conduct pre-movement protocol and depart the fire station. Each stage of the turnout process is now described in more detail.

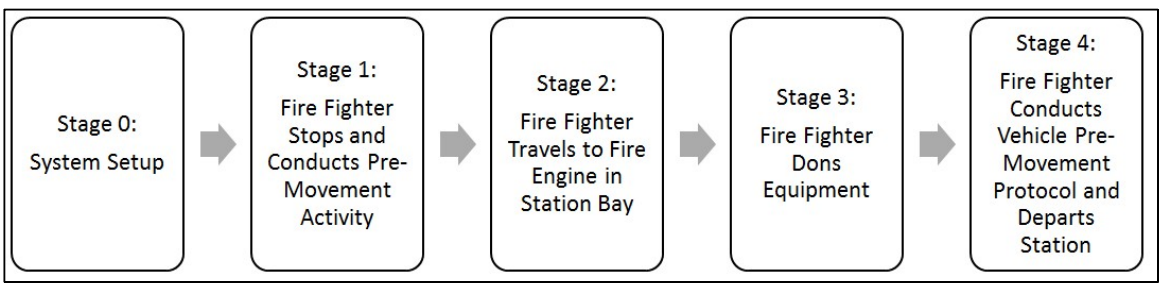


Figure 3: Five Key Firefighter Turnout Stages

3.3.1 Stage 0: System Setup

The initial state of the fire station is the precursor to determining the actions firefighters take when egressing a fire station. The components of this stage include the percentage of calls by call type, the number of firefighters required for the call type, and the occupancy rates for the eight functional areas of a typical fire station (Figure 4).

Fire stations, as a best practice, record the call type and the total response time for each emergency call they receive ("CFAI," 2016). The emergency call types recorded include, but are not limited to, structural fire, hazardous material, chemical, biological, radiological, nuclear, explosive, airfield emergency, technical rescue emergencies, and routine medical emergencies. This model separates call types into three emergency categories: medical, structural, and other. Analyzing the case study fire station's call records showed that 41% of calls were medical, 57% were structural, and 2% were categorized as other. It is important to know the likelihood of each call type because the call type initiates how many firefighters will respond. The NFPA requires a crew of at least two firefighters must respond for medical, four for structural, and up to eight for other responses.

The job of the responding firefighters is also important because the different jobs require different preparation times. This model assigns one of three jobs to each firefighter. The first job is the driver, sometimes referred to as the driver operator or engineer, who sits in the front left driver position of the response vehicle. The second job is the navigator who sits in the front right of the vehicle. This position is usually filled by the crew chief or officer. The third job is the passenger, who sits in one of the remaining seats of the emergency response vehicle. For structural calls, one is assigned as the driver, one is assigned as the navigator, and two are assigned to be passengers. For medical calls, one firefighter is assigned as the driver, and one is assigned as a navigator. For other calls, one is assigned as the driver, one is assigned as the navigator, and six are assigned to be passengers.

U.S. fire station spaces typically contain the following areas: dormitories, kitchen, restrooms and showers, recreation room, gym, training room, administrative offices, and equipment and vehicle bay ("Unified Facilities Criteria 4-730-10 Fire Stations," 2006).

While many additional rooms and areas are common in fire stations, these eight areas were chosen as being the key rooms firefighters occupy the most. The occupancy rates for each room were determined by multiple subject matter experts from the fire station and observation. The occupancy rates describe the percentage of time a single fire fighter spends in each area throughout the day. The responses from the subject matter experts were averaged and found to mimic the observed percentages. The room occupancy by percentage can be seen in Table 1. Each firefighter acts independently of the next throughout the remainder of the model and does not act as a single unit again until all firefighters are in the fire engine and departing the station.

Table 1: Fire Fighter Daily Room Occupancy

Room	Percentage of Day Occupied
Dormitory	22%
Kitchen	20%
Restrooms and Showers	5%
Recreation Room	19%
Gym	7%
Training Room	10%
Adminstrative Offices	3%
Equipment and Vehichle Bay	14%

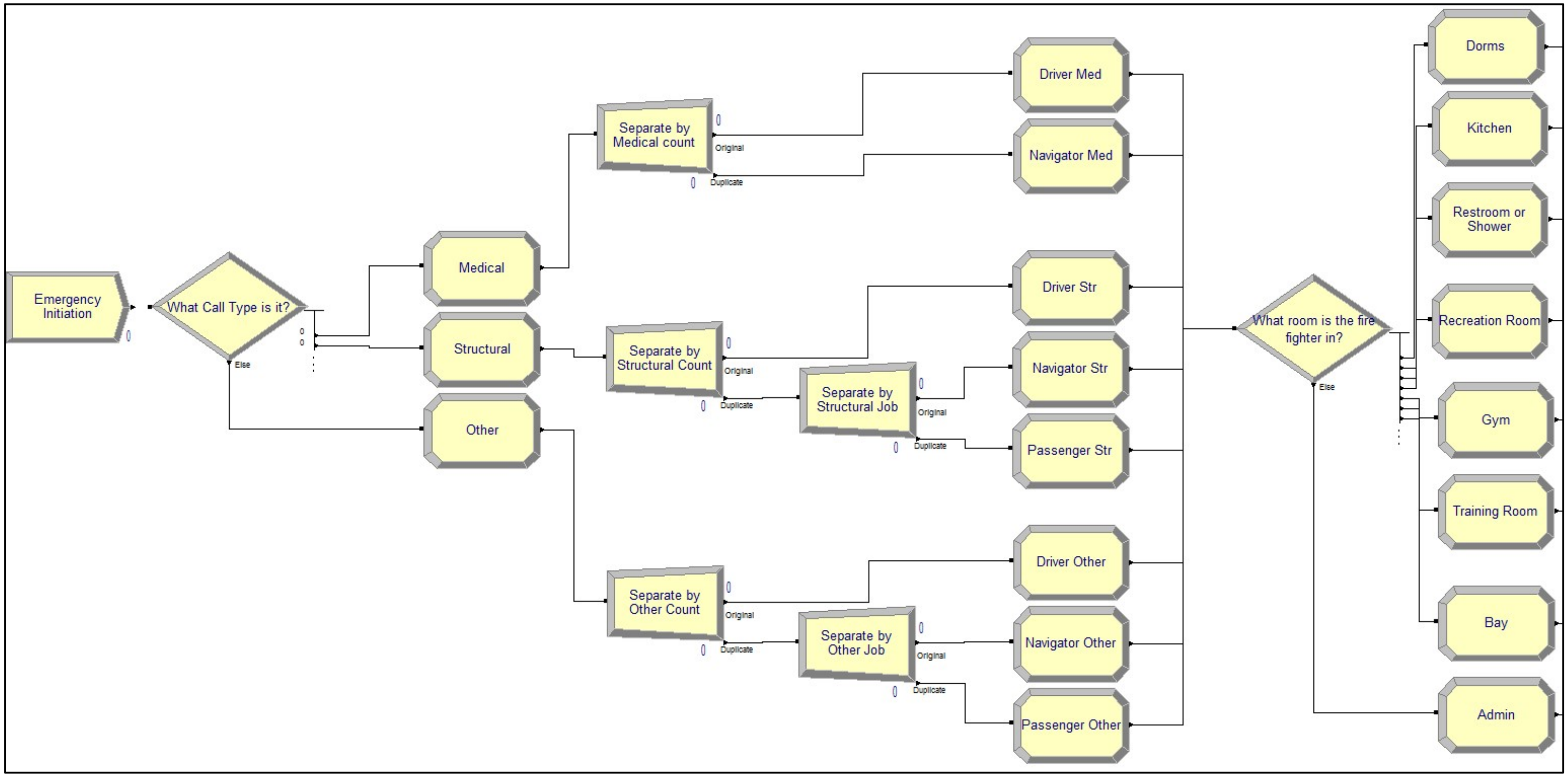


Figure 4: ARENA Stage 0

3.3.2 Stage 1: Firefighters Stop Current Activity

During Stage 0, firefighters were assigned to different rooms within the fire station and were pre-assigned a role telling them what order of call they will take and the type of call to which they will respond. In this step, when the dispatch call comes over the intercom system, all firefighters stop their current activity and perform pre-movement actions such as logging out of a computer, turning off an oven, waking up, or getting off of fitness equipment (Figure 5). Research has found that humans normally do not elicit an immediate response to an alarm and spend time conducting pre-movement actions (Canter et al., 1980; Sime, 1985). Proulx (1994) discovered that this delay was not minimal and ranged greatly depending upon several occupant characteristics, such as gender, age, physical ability, familiarity with a building, experience, training, peer and leader influences, and the emotional state of the individual. Observations and subject matter expert interviews were used to determine the range of times it takes a firefighter to stop their current activity and perform pre-movement activities. These results can be seen in Table 2.

Table 2: Stage 1 Activity Times

Room	Time Range for Stage 1 (Seconds)		
	Minimum	Maximum	Most Likely
Dormitory	5	35	20
Kitchen	5	20	10
Restrooms and Showers	10	30	15
Recreation Room	3	15	5
Gym	5	15	7
Training Room	5	20	7
Adminstrative Offices	5	10	7
Equipment and Vehichle Bay	5	10	7

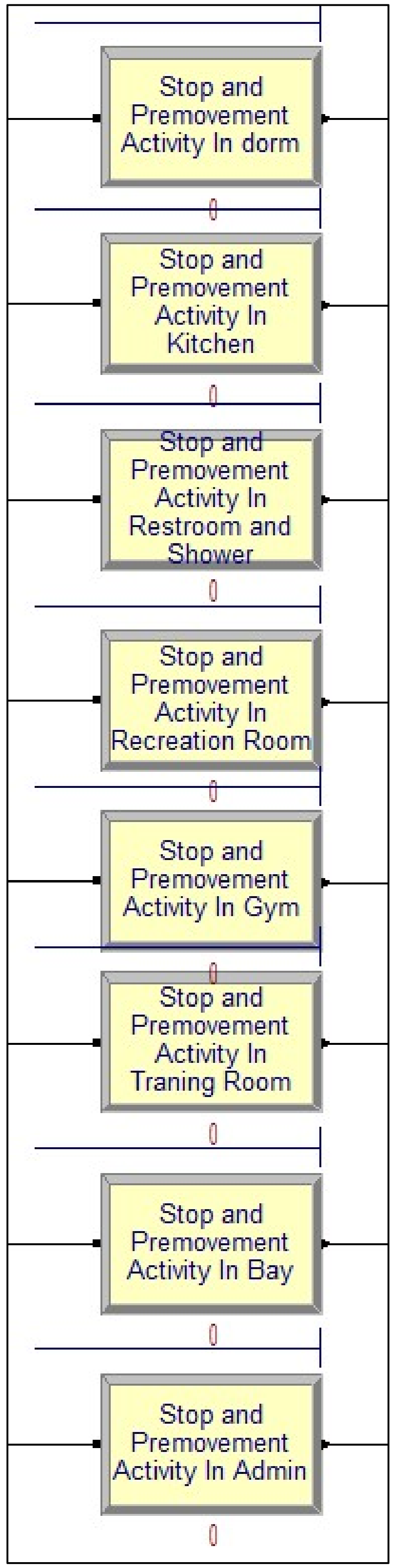


Figure 5: ARENA Stage 1

3.3.3 Stage 2: Firefighters Travel to Fire Engine in Station Bay

During this step, the firefighters need to egress the specific room in which they are located and decide the most direct route to the station bay. They then need to travel to the station bay and their specific fire apparatus as quickly as possible without violating any rules, such as running (Figure 6). To determine the range of time needed to travel from each room to the station bay, rate of travel and distances measured from the fire station as-built blueprints were used. Distances were measured using the shortest distance from the center of the occupied room to the center of the station bay using rectangular paths. These paths contain only straight lines and right angles. The use of rectangular distance measuring has been shown to provide a good approximation of the actual distances between rooms of a facility (Glenn & Vergara, 2016).

The rate of travel for firefighters moving from their in-garrison position to an emergency vehicle during an alarm scenario can influence the speed at which the first response team can provide their services. Walking speeds vary depending on age, sex, body composition, and physical ability (Himann et al., 1988). In the U.S. 75% of firefighters are between the age of 20 and 50 and are predominantly male (“NFPA,” 2016). Bohannon (1997) shows the mean comfortable gait speed for males between the age of 20 and 50 is 4.6 ft/s and the mean maximum walking speed for the same age group to be 8.2 ft/s. These values were used as the travel speed maximum and minimum parameters within the model to determine the time needed to travel a certain distance. This was accomplished by dividing the distance from each functional area to the station bay by 4.6 ft/s to find the maximum travel time, 8.2 ft/s to find the minimum travel time, and 6.4 ft/s to find the minimum travel time. The values for each room were input into the model using a triangular distribution.

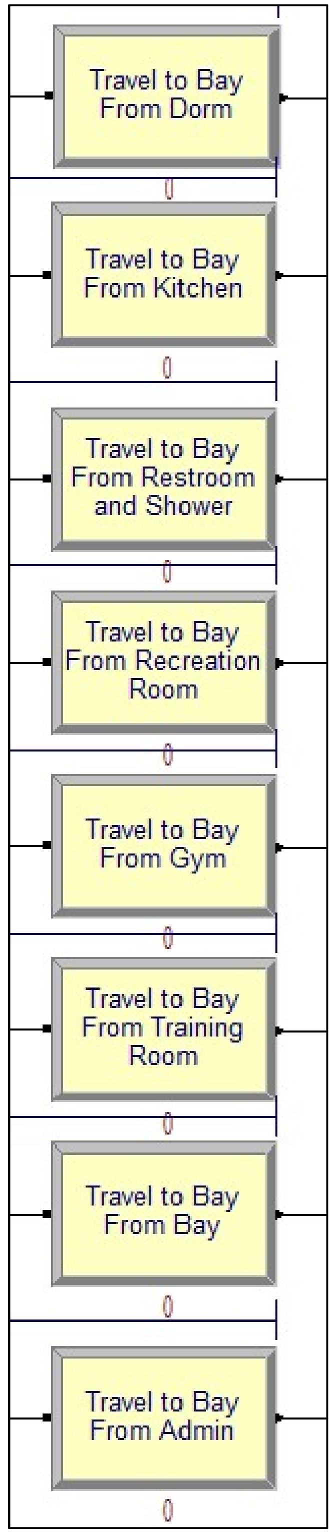


Figure 6: ARENA Stage 2

3.3.4 Stage 3: Firefighters Don Equipment

During this step, the firefighters will don all protective equipment based on the call type (Figure 7). This equipment includes bunker gear, self-contained breathing apparatus, helmets, and many other safety items. This stage's time parameter consists of the total time it takes the firefighters to don the correct safety gear based upon the call type. The activity times based on observations and subject matter expert interviews for donning equipment are shown in Table 3.

Table 3: Stage 3 Activity Times

Call Type	Time Range for Stage 3 (Seconds)		
	Minimum	Maximum	Most Likely
Medical	10	25	15
Structural	20	60	25
Other	20	60	35

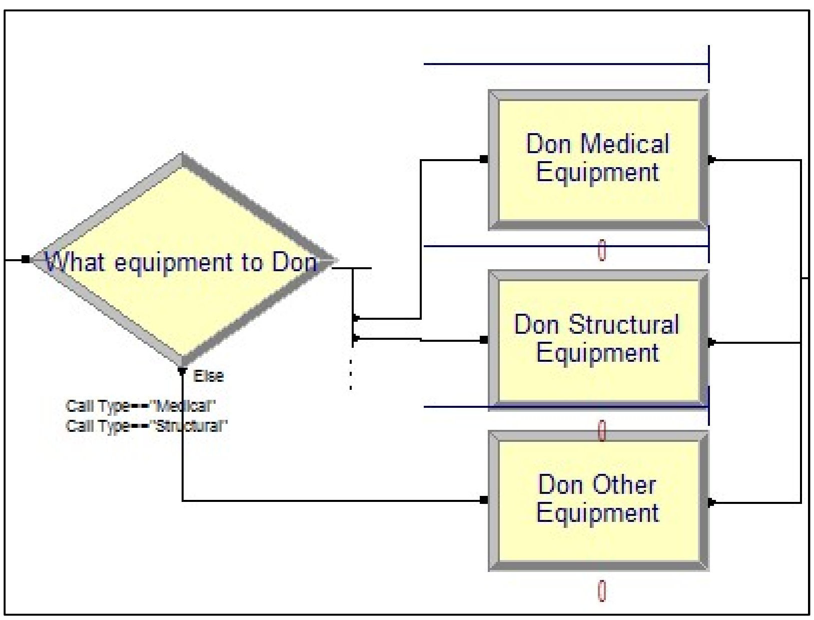


Figure 7: ARENA Stage 3

3.3.5 Step 4: Conduct Pre-Movement Protocol and Depart Station.

During this step, the firefighters, depending upon their pre-determined role, execute pre-movement operations such as inspecting the fire engine, disconnecting the air hose from the fire engine, starting the fire engine, inputting directions into the GPS system, and putting on seat belts (Figure 8). The stage's parameters consist of the time it takes for each firefighter to complete the procedures for the role they were preassigned and to get into the fire engine. The ranges of time needed to complete the pre-vehicle movement protocol for the predetermined jobs and for the fire engine to depart the station were based on observations and subject matter expert inputs. The results are shown in Table 4.

Table 4: Stage 4 Activity Times

Job Type	Time Range for Stage 4 (Seconds)		
	Minimum	Maximum	Most Likely
Driver	10	25	20
Navigator	5	20	15
Passenger	5	15	10

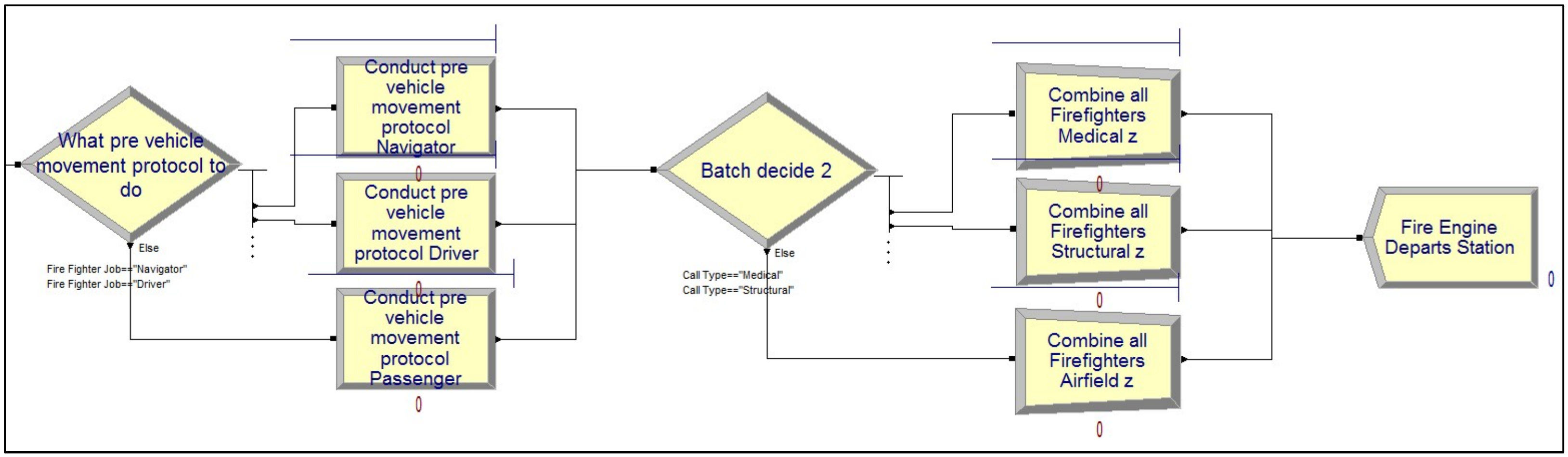


Figure 8: ARENA Stage 4

3.3.6 Model Assumptions

Additionally, four assumptions were made: (1) only one response can be run at a time and simultaneous responses will not occur, (2) subject matter expert inputs are correct, (3) flow of processes conducted will not change, and (4) no failures will exist in the system.

<u>Assumption #1:</u>

Only one response can be run at a single time and simultaneous responses will not occur. The purpose of this model is not to determine needed resource and staffing levels at fire departments. To that end, it is assumed that each model simulation run is independent of the next.

<u>Assumption #2:</u>

Assume subject matter expert inputs are correct. Due to limited real-world calls conducted by the fire station, experts were interviewed to provide further insight into the turn-out time process and the data needed to develop a model. The subject matter experts consisted of over 25 personnel both veteran administrative supervisors and mid-level firefighters who have been working within the fire station for years. Their experience and knowledge of the daily actions conducted at the fire station qualify them as reliable individuals to interview. The information garnered from these individuals was verified by comparing the limited real-world call data to turn-out time practice runs. The compilation of information collected from interviewing the subject matter experts was assumed to be accurate for all areas.

Assumption #3:

Flow of processes conducted will not change. If the flow of the turnout time processes changes from the model flow, then the model will be rendered obsolete and not represent the current system or be useful in determining improvement recommendations.

Assumption #4:

Assume there will be no failures in the system. A failure in the model will render false results and skew the validity of the model. A failure could include an alarm system malfunction, broken equipment items, or any failure that is not normal to the usual turnout time process.

3.3.7 Model Validation

Model validation for the case study was conducted by statistically comparing the simulated turnout time results with real-world data. Baseline model validation was conducted using a Student's t-test. The baseline simulation data was compared to five years of data (N=482) collected by the fire station for the actual time it took to complete the phases of turnout. The results of the test, $t(299)=2.33$ and $p=0.59$, support the finding that the baseline model and reality are statistically equivalent.

3.4. Model Effectiveness as a Design Tool

To determine the model's effectiveness as a design tool for fire stations around the United States, blueprints and turnout time data logs were gathered for nine fire stations with dissimilar layout characteristics. The case study fire station is located in Ohio, five fire stations are located in California, and four fire stations are located in Colorado. The fire stations represent both large and small fire stations with average travel distances ranging from 50ft to 180ft. The fire stations all have different as-built blueprints; eight of the stations are single story facilities, and two of the stations are multi-storied. Furthermore, the total facility area ranges from 4,700 sq-ft to 34,000 sq-ft.

The response variable being validated is the total turnout time. Before testing the model's effectiveness for other fire stations, the percentage of medical, structural, and other call types were changed from 41% medical, 57% structural, and 2% other to 55% medical, 43% structural, and 2%. This was based on the advice from subject matter experts at the case study fire station due to the uncommon call percentages their station receives. The new percentages were found by combining the call percentage metrics received from all ten fire stations. The only model input parameter for each fire station simulation was the travel distance firefighters must traverse between the center of the room they occupied at the beginning of the emergency notification to the center of the fire station bay.

The simulated results were compared to the real-world data for each of the ten fire stations using a Student's t-test to validate its ability to predict the station's turnout time. Figure 10 shows the model is statistically effective at predicting fire station turnout time based upon facility layout.

Distance From Room to Station Bay (Feet)									
Fire Station	Dorm	Kitchen	Restroom	Recreation	Gym	Training	Bay	Admin	AVERAGE
Baseline	151	193	173	220	186	127	0	201	178.7
#1	51	110	101	108	108	138	0	78	99.1
#2	112	89	155	53	121	88	0	78	99.4
#3	79	92	65	60	65	61	0	66	69.7
#4	48	79	70	61	49	60	0	54	60.1
#5	72	72	82	55	115	66	0	53	73.6
#6	70	59	37	40	44	49	0	60	51.3
#7	85	54	61	64	69	42	0	63	62.6
#8	115	54	63	60	80	65	0	50	69.6
#9	120	56	50	75	77	76	0	41	70.7

Figure 9: Distance Measurements

Fire Station	T-Test	Mean (seconds)		Standard Deviation		95% Upper Bound (seconds)		95% Lower Bound (seconds)		Number	
		Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated
Baseline	0.543	82.6	83.7	0.377	0.279	85.7	85.6	79.5	81.8	203	300
#1	0.327	73.8	75.6	0.327	0.254	77.6	77.4	69.9	73.9	101	300
#2	0.385	73.7	76.6	0.382	0.287	81.7	78.5	65.6	74.7	31	300
#3	0.291	65.6	71.7	0.357	0.264	80.5	73.5	50.8	69.9	8	300
#4	0.064	72.5	69.4	0.342	0.252	75.6	71.1	69.3	67.7	165	300
#5	0.717	73.3	72.0	0.324	0.260	81.6	73.8	65.0	70.2	21	300
#6	0.665	70.2	68.7	0.205	0.261	75.6	70.5	64.9	66.9	20	300
#7	0.091	67.6	70.7	0.290	0.272	70.8	72.6	64.3	68.9	108	300
#8	0.450	74.8	73.2	0.302	0.287	78.5	75.1	71.0	71.2	90	300
#9	0.094	77.5	74.0	0.342	0.282	81.4	75.9	73.6	72.1	106	300

Figure 10: Student's T-Test Results for Model Effectiveness (Alpha=0.05)

3.5. Using the Model as a Design Tool

This simulation model, in tandem with risk assessment, can be used to evaluate proposed fire station designs. Design professionals and building decision-makers can use this model in a myriad of ways. This section of the paper will discuss four distinct uses: compare multiple design options, find optimal design solutions by reevaluating room placements for a given area constraint, determine a layout to meet an egress standard, and more effectively plan emergency response capabilities.

3.5.1 Use 1: Compare Multiple Design Options

Comparing multiple design options involves finding the shortest distance (using right angles) a firefighter must travel from the center of each room to the center of the station bay and inputting those travel distances into the model. For example, if the hypothetical fire station designs in Figure 11 were compared, a ranking of the lowest turnout time to highest could be determined, and the best option with respect to response capability could be chosen. Using simulation to compare design options results in different and more accurate results than simply calculating the average distance between station areas because simulation can account for the uncertainty that a distance calculation cannot.

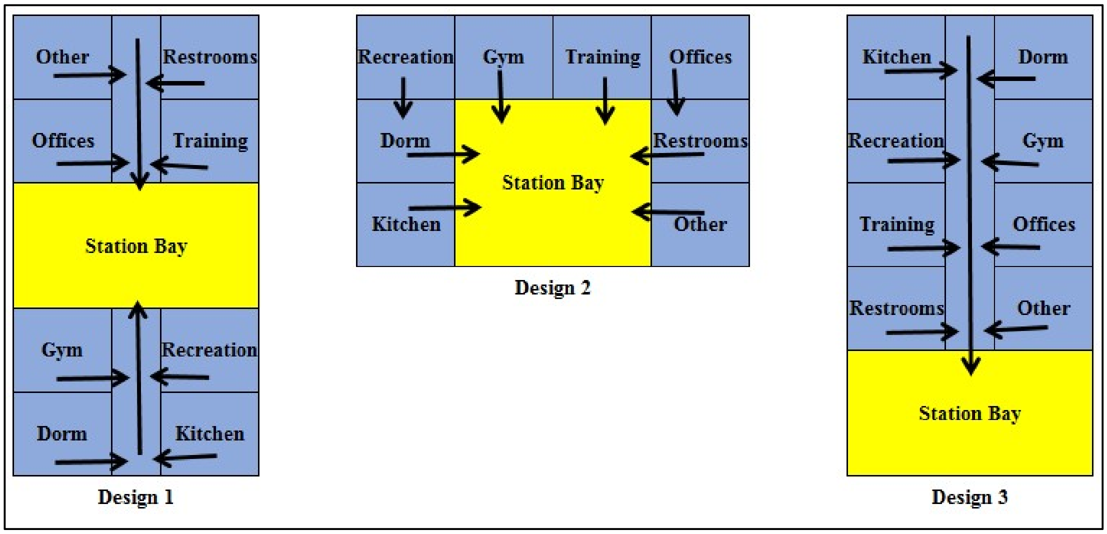


Figure 11: Comparison Fire Station Designs

3.5.2 Use 2: Find Optimal Design Solutions by Revaluating Room Placements

Finding an optimal solution, given a set footprint is also an option this simulation model provides. For example, if the size and shape of a building were constrained such as in a remodeling effort or in crowded cities where expansion capability is limited, the fire station design team can find the best location for each room. This could be accomplished by testing the options available. Figure 12 shows three hypothetical designs with a constrained area where rooms have been reconfigured. For this model containing eight areas, there would be a total of 5,040 possible options to test.

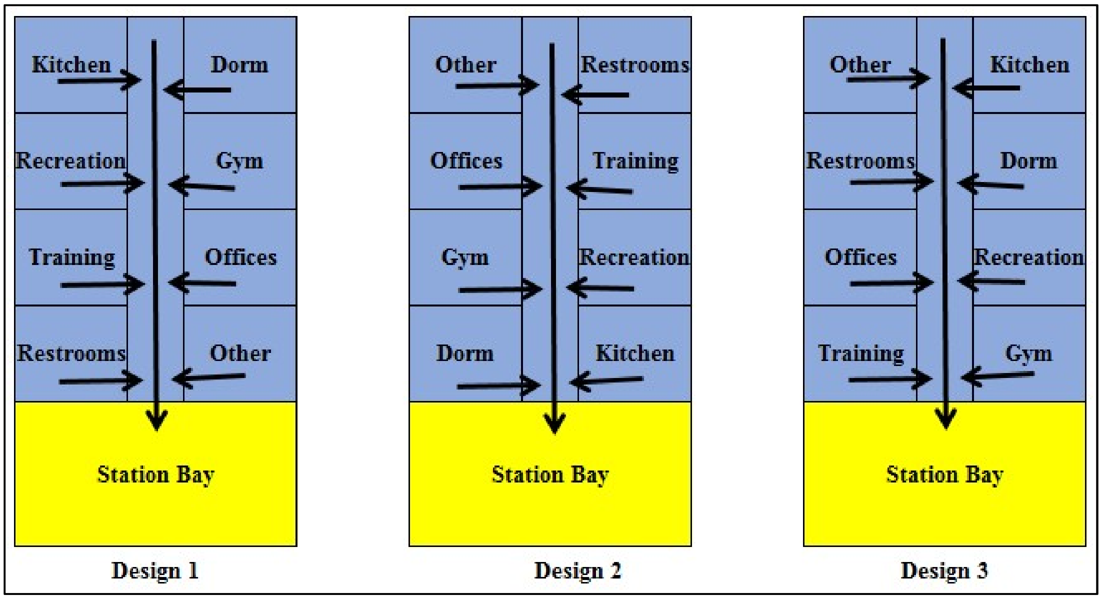
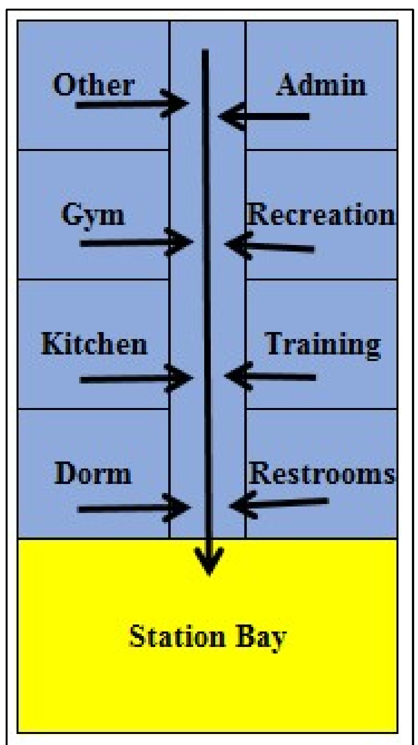


Figure 12: Three Optimization Design Options

It would be cumbersome and inefficient to test all 5,040 design options. To combat this, a ranking from least travel distance to most travel distance is a possible way to find the optimal or near optimal room location. For the eight areas considered in this research, the location with respect to the station bay was determined. To find the optimal order from the station bay the following steps were made to the model. First, equal travel times to the station bay for each room were input into the model. Doing so makes travel time irrelevant to the overall turnout time from each room. It also makes pre-movement activity the only activity on which to base room location. Because each pre-movement activity has a skewed triangular distribution, simply ranking the rooms by mean pre-movement time cannot be done. Instead, each room needs to be simulated independently in the model to determine the effect each rooms pre-movement activity has on the entire network. To do this, assign the room occupation percent to 100 percent and run the simulation for each room. Doing so tells the model that every fire fighter is in the same room for every run. Next, record the average run time for each room and rank the turnout times from highest time to lowest time (see Figure 13). Assigning room location congruent with the ranked room orders will result in a near optimized layout because it puts rooms with a lower turnout affect further from the bay and rooms that have a greater affect on turnout time to be closer to the station bay. Figure 14 shows a near optimal layout for this hypothetical scenario. Designers should create layouts where room locations are consistent with the list shown in Figure 13.

Optimization Ranking		
Room	Mean (minutes)	Location in Design
Dorm	1.1455	Least Travel Distance to Station Bay
Restroom/Showers	1.1042	
Kitchen	0.9851	
Training Room	0.9692	
Gym	0.9337	
Recreation Room	0.9154	
Admin	0.9034	Most Travel Distance From Station Bay

Figure 13: Optimization Fire Station Design



Optimized Design Example

Figure 14: Optimized Design Example

3.5.3 Use 3: Determine Layout to Meet an Egress Standard

Third, this simulation model can determine a maximum turnout time standard based on distance. The NFPA recommends less than 80 seconds for structural responses and 60 seconds for medical responses. The data collected from the ten fire stations shows that roughly 55% of all calls were medical and 45% were structural. Using weighted averages, the suggested maximum mean simulated time would be 69 seconds. Design professionals could then create several design solutions with predicted turnout time under this maximum mean. This capability could allow decision-makers to make more informed decisions and decide if other factors such as cost or time to construct are more important than the fastest turnout time when more than one design option meets the NFPA requirements.

3.5.4 Use 4: Plan Emergency Response Capabilities

This model is also helpful when creating a full emergency service system. It can be used to determine the number of fire stations required for a given area. For example, knowing the probable time it would take to turnout from several fire stations within a city could help city planners determine the spacing needed between fire stations to meet NFPA standards; higher turnout times mean stations are closer together and could potentially add fire stations to the city, while low turnout times mean stations could be spaced further apart and potentially reduce the total number needed.

3.6. Discussion

Decision-makers have several options to choose from when conducting decision analysis such as FMEA, reliability analysis, multiple-criteria analysis, fuzzy set theory, and outranking approaches. Risk and decision analysis related to facility design are commonly unstructured where the alternative option comparisons are vague, difficult to contrast, or cannot be easily measured with respect to the facility's purpose. The previously discussed uses for this model inadvertently assumes that turnout time is the most important factor when constructing new fire stations. In reality, many other factors play a role in the design finally chosen. This model provides a tool to quantitatively measure the operational effectiveness of a facility's purpose that does not solely rely on the expertise of the designer or decision-maker. This capability allows decision-makers to more consistently choose the correct design based on the decision makers criteria and reduces the guesswork common for the hard to measure aspects of facility planning.

3.7. Conclusion

Overall, this research presents a fire station design tool that engineers and facility owners can use in tandem with risk assessment methods such as FMEA or reliability analysis to design fire stations that aid in its emergency response capability. There are many options for a fire station design and choosing the correct design may require making several decisions or be subject to constraints such as cost, time to construct, operational effectiveness, and impact on the environment. This model can provide a decision support tool to the decision-maker by predicting the operational effectiveness in terms of turnout time of a proposed fire station design. The model can be utilized by fire station design experts to help improve their layouts to improve turnout time and enhance its ability to provide vital services to the community. The model was created in such a way as to be usable for all fire station sizes and layouts with the only user input being the distance between the center of eight key fire station rooms and the center of the station's vehicle bay. This research shows that discrete-event simulation is a useful method for extending a facility layout problem to non-production facilities because it can translate the interactions between a facility's layout and the processes performed within the facility into an operational effectiveness measure. Applying similar approaches to new construction projects can enhance the understanding a decision-maker has to the effects of a building's design on its ability to perform the intended purpose for the facility.

Future work in this research should include improving the current model to increase its predictive capability. The method could also be extended to other industries where travel time is important, such as airports or theme parks, to measure operational effectiveness and give the decision-maker more clarity.

4. Conclusion and Recommendations

Turnout time is an important part of the emergency response system. Turnout makes it essential to consider the fire station as an integral component to successfully and effectively respond to an emergency. This research answered four investigative questions pertaining to fire stations and the role it plays in emergency response. The first two questions concerned the facility layout problem to improve an existing fire station, and the second two questions concerned the facility layout problem to aid with the design of new fire stations. These questions were guided by the overall purpose of the research: to understand how the operational effectiveness of fire stations can be improved by applying simulation to facility layouts.

4.1 Investigative Questions

The four investigative questions were answered. The questions were addressed by the articles in Chapter 2 and Chapter 3 using discrete-event simulation and determined the following findings and insights.

Question #1:

What are the key Configurable, Environmental, Procedural, and Behavioral risk factors that affect turnout time at the case study fire station?

These risk factors take into account the physical characteristics of the building, the individual agent interactions that occur between stimuli within the station's environment, and the choices a person must make in response to those stimuli. Multiple factors were found to affect turnout time in the literature (Figure 18), but the key factors at the case study fire station were garage opening time (procedural), dispatch procedures (procedural and behavioral), and the facility's layout (configurable). This research did not find any key environmental factors. Finding the significant factors via this research's method eliminates potentially wasteful initiatives based on guesswork and instead allows emergency responders to develop targeted and impactful solutions.

Question #2:

What changes can be implemented at the case study fire station to reduce turnout time and what are the predicted impacts of the changes?

Three alternative models were created to remedy the effects of the identified risk factors. Implementing a procedural change to allow a dispatcher to open the garage door via the dispatch center when the call first comes in saved 4.2 seconds and reduced the likelihood that the garage door was the factor inhibiting the fire truck from leaving the station. This change resulted in a predicted turnout time reduction of 3%. The second alternative model implemented a procedural and behavioral change giving the dispatch center the ability to pre-warn firefighters of an impending call and saved 33.6 seconds. This occurred by giving the dispatcher the ability to alert firefighters before completing the emergency call. This change resulted in a predicted turnout time reduction of nearly 25%. The third alternative model implemented a configurable change and included changing the room placement within the station such that the rooms with the highest occupancy rate were closer to the bay than rooms with a lower occupancy rate. This change resulted in a savings of 1.8 seconds, which represented a 1.15% reduction in predicted turnout time. These findings show that applying even simple changes have the potential to enhance first responder ability. It also showed that, for the case study fire station, early warning systems are more important than the layout.

Question #3:

How effective is the case study simulation model at predicting fire station turnout time for other fire stations based upon facility layout?

The baseline model was validated using a Student's t-test with an alpha of 0.05 against nine additional fire stations of all shapes, sizes, layouts, and stories with only the layout parameters being changed. The model failed to reject the null hypothesis for all stations, thus showing that the model is effective at predicting a fire station's turnout time based on facility layout.

Question #4:

How can the simulation model be used to evaluate proposed fire station designs?

The model can be used in four applications: comparison, optimal design, layout to meet a standard, and in emergency system planning. Comparison applications can determine the best design given several options. This is beneficial in contract selection scenarios for new construction when decision-makers are faced with choosing between several different designs. Optimal design applications can aid fire station designers to create the most operationally effective design given a constrained building footprint. Layout to meet minimum standard applications can allow designers to put more focus on other building performance and cost factors while still ensuring an operationally effective building. Emergency system planning applications can be used when determining fire station locations within a city. Knowing total response times will allow city planners to space fire stations apart based on the total response times of each station.

4.2 Recommendations for Future Research

While this research successfully answered the research questions and fulfilled the research purpose, there are still areas that can be expanded and further improved.

4.2.1 Improve Existing Design Tool

Future research could focus on refining the current model. This could be accomplished by collecting more data and including more functional rooms than the eight deemed essential in this research. Doing so, could increase the model's accuracy and provide a better tool for designers to use in search of an optimal fire station design.

4.2.2 Automate Fire Station Optimization

Chapter III offered an approach to finding an optimal design solution. That solutions efficiency, however, can be improved upon. Future research could enhance the current design tool and provide designers with the optimal layout of a fire station given a facility footprint and room size constraints. Doing so could maximize a facility’s operational effectiveness while potentially decreasing design costs.

4.2.3 Application of Methodology to Other Facility Types

The success of this research further supports the use of discrete-event simulation for facility design. Using comparable methods at other facility types could enhance facility infrastructures role in operational effectiveness.

4.3 Significance of Research

This research showed that using discrete-event simulation to reduce fire station turnout time is achievable both in existing facilities and in new construction endeavors. The model created, and methodologies associated with its creation, can highlight improvement areas for existing facilities and predict the turnout time for both corrective measures and for proposed designs. The use of this method for fire stations will allow for reduced turnout times, thereby giving first responders the ability to more effectivley provide life, limb, and property saving services.

Appendix A. Literature Review

Emergency response is a fundamental government service. Safe and prosperous municipalities depend on emergency services. In order to effectively respond to a crisis, a system of plans, authorities, policies, procedures, personnel, training, materials, equipment and facilities must function together towards a common goal (Jackson et al., 2011). How to successfully combine these elements to work together efficiently, consistently, and dependably has been the goal of emergency research since its inception. Emergency management research is typically focused on improving the reliability of emergency management and response capabilities (Abrahamsson et al., 2010; Ball & Lin, 1993; Henstra, 2010; Jackson et al., 2010), yet, limited literature exists on the impact the facility may have on the system.

Facilities can be an integral part of the efficient workings of any system. Within communities many emergency facilities exist, such as emergency operation centers, dispatch centers, police stations, hospitals, and fire stations; the effectiveness of the community's emergency response system depends on both the location and internal configuration. While enhanced facility layout can provide improvements across the board, the best opportunity to find potential response gains from the facility layout is at the fire station because firefighters are the most likely to respond to an emergency ("FEMA Chapter 9 - Preparedness for Emergency Response," 2016) and as such offers the best location to search for potential response gains. The literature that does exist concerning fire stations as part of the emergency response system focuses on facility placement within a community (Badri, Mortagy, & Alsayed, 1998; Plane & Hendrick, 1977; Schreuder, 1981; Tzeng & Chen, 1999; Yang, Jones, & Yang, 2007) with the architectural configuration receiving limited attention (Stauber, 2003; Weninger, 2004). US Fire Stations typically contain the following functions: dormitories, kitchen, restrooms and showers, recreation room, gym, training room, administrative offices, equipment and vehicle bay ("Unified Facilities Criteria 4-730-10 Fire Stations," 2006). While these basic fire station requirements remain consistent across the U.S., nearly every fire department layout is different. Even standard design fire stations such as those found within the Army Corps of Engineer's portfolio are altered to fit the specific desires of the community that builds it. In many cases, facility design is controlled by the availability of space, conservation of the environment, welfare and safety of the occupant, and the lifecycle cost (Faber & Stewart, 2003). Rarely is a facility's ability to act in concert with the function it houses considered a key design factor with the exception of production facilities, which leads to the purpose of this research.

The purpose of this research is to understand how the operational effectiveness of fire stations can be improved by applying configurable, environmental, procedural, and behavioral factors. The literature review will begin by defining operational effectiveness in Section A.1. Next, in Section A.2, the literature review will define configurable, environmental, procedural, and behavioral factors. This research will apply simulation tools to answer the research question. Thus, in Section A.3, simulation as a tool will be introduced. As a methodology, this research will apply the facility layout problem. This problem will be discussed in Section A.3.1. The facility layout problem has not been used in the context of emergency services; however, simulation has frequently been used to solve emergency response problems. Therefore, in Section A.3.2, I will review past applications of simulation in emergency response. Section A.3.3 will present risk assessment tools.

A.1 Operational Effectiveness

For this research, operation effectiveness is defined as any kind of practice that allows a fire station to maximize its ability to meet all regulations and societal expectations as well as maximize its ability to provide emergency aid to the community it serves. The National Fire Protection Agency (NFPA) require first responders be timely in their response to an emergency call. The NFPA defines Total Response Time as the time interval from the receipt of the alarm at the primary station of responsibility to when the first emergency response personnel begin initiating an action or intervening to control the incident. To be accredited, all fire stations must measure the Total Response Time and meet a minimum level of service ("CFAI," 2016). DoDI 6055.06 requires different first responder arrival rates and staffing quotas for several different emergency types. Structural fire, HAZMAT/CBRNE, and Technical Rescue emergency's require the first arriving company be at the emergency within 7 minutes of the initial notification with a crew of at least four firefighters. Medical emergencies also require the first arriving company to be in place within 7 minutes but only with a staff of two firefighters.

For nearly every emergency type, the Total Response Time for the first arriving company is set to 7 minutes. NFPA 1710 more specifically details the goals for each of the three parts of Total Response Time. Those three parts are alarm handling time, egress time, and travel time. This document suggests the fire department shall establish a performance objective of having an alarm answering time of not more than 15 seconds for at least 95 percent of the alarms received and not more than 40 seconds for at least 99 percent of the alarms received, an 80 second egress time for fire and special operations response and a 60 second egress time for EMS response, and 240 seconds or less travel time for the arrival of the first arriving engine company at a fire suppression or EMS incident (“NFPA,” 2016). Furthermore, the NFPA suggests a maximum 120-second total turnout time. Turnout time involves both alarm answering time and egress time. Of the Total Response Time, two minutes out of seven or nearly one-third of the time spent responding to an emergency occurs within a facility. Since firefighters spend so much time in the facility, we need to look at configurable, environmental, procedural, and behavioral factors.

A.2 Configurable, Environmental, Procedural, and Behavioral Factors

When engineers use risk assessment in facility design, they commonly focus on welfare, safety, resource allocation, and structural and mechanical hazard potentials. These aspects of facility design are important in reducing risk both in the built environment and when completing life cycle analysis (Kam & Fischer, 2004). These aspects should not be ignored as they represent many safety and building efficiency related facets concomitant with any facility design and construction effort focused on building sustainable, cost effective, and productive facilities. Furthermore, current societal pressures make conservation of the environment, the welfare and safety of the individual, the optimal allocation of resources, and the facility’s structural, aesthetic, and mechanical productivity and efficiency large priorities in the design and construction profession (Faber & Stewart, 2003). However, risk factors go beyond the physical attributes or the systematic procedures many use to determine which factors are more significant than another. The factors used in today's process design procedures are important, but other potential risks, deserving of equal attention, include configuration, procedural, environmental, and behavioral risks (Gwynne et al., 1999). These factors are crucial in determining in a holistic manner how to mitigate the risks inherent within facility performance. The factors identified by Gwynne et al. mirror results found in an interview the Green Bay Fire Department conducted of 104 Fire Station Chiefs asking them what factors most affected turnout time (Stauber, 2003). The results shown in Figure 15 outline the fire chiefs' top reasons influencing turnout time.

Configurational	**Environmental**	**Procedural**	**Behavioral**
Design/Layout of Station	Time of Day	Length of Dispatch Message	Activity at Time of Call
Personnel Location in Station	Noise/Poor Dispatch Message Quality	Equipment Requirements	Slow Personnel
		Type of Call	Personnel attitude

Figure 15: Stauber's Top Factors Influencing Turnout Time

Configurable aspects concerning turnout time include well-established requirements such as those contained in the International Building Code and NFPA documents that dictate details such as number of exits, exit widths, and health requirements (Mesagna & Raroni, 1991; “NFPA,” 2016, “Unified Facilities Criteria 4-730-10 Fire Stations,” 2006). Many other aspects are not cemented in code and consist of design freedoms such as the buildings layout, travel distance between rooms, the proximity between facility functions, how many corners must be navigated to exit a building. Proulx (2001) found several building characteristics important for design professionals to consider when determining the egress capability of personnel during evacuations. These characteristics included building type, architectural details, facility function, and evacuation controls within the facility. These characteristics can be applied to fire station turnout because firefighters, when responding to an emergency, are essentially trying to egress or evacuate the fire station they are in as quickly as possible. The characteristics applicable to fire station egress include the number of floors, floor area, the location of exits, the location of stairwells, the complexity of the space and wayfinding, building shape, visual access to exits.

Weninger (2004) developed a fire station design turnout time efficiency rating method to help guide designers in their ability to create an efficient station layout. He did this by taking into account the distance needed to travel through hallways, down fire poles, and downstairs from a fire station room to the emergency response vehicle, and the number of hours spent in each room by the typical firefighter. He assigned travel speed coefficients of .15 seconds per foot (6.67 ft/s) for hallway travel, .21 seconds per foot (4.76 ft/s) of fire pole travel, and .25 seconds per foot (4.00 ft/s) for stair travel to determine the time a firefighter would be expected to reach the apparatus. His room efficiency rating was determined by adding the time needed to travel to the apparatus from a particular room multiplied the number of hours spent in that room. To that end, a lower score is preferable to a high score. This method was used to determine the best station design for turnout time in the county Weninger resided by comparing 13 fire station designs based on the overall daytime and nighttime efficiency rating. An example of the form is shown in Figure 16.

FIRE STATION ROOM	DISTANCE TO APPARATUS	FIRE POLE Ft	STAIRS # treads	TOTAL Time to arrive at apparatus	Hours spent in room	Room efficiency rating
Dayroom	111' x .15	12.0 x .21	0 x.25	19.07 sec	2.12	40.43
Kitchen/ Dinning room	153' x .15	12.0 x .21	0 x.25	25.52	2.34	59.72
Men's Locker Room	81' x .15	12.0 x .21	0 x.25	14.72	.085	12.51
Women's Locker Room	90' x .15	12.0 x .21	0 x.25	16.07	0.073	1.17
Line Office	97' x .15	12.0 x .21	0 x.25	17.12	3.57	61.12
Workshop	50' x .15	0	0 x.25	7.5	0.57	4.27
Laundry room	125' x .15	12.0 x .21	0 x.25	21.32	0.34	7.25
Workout room	105' x .15	12.0 x .21	0 x.25	18.32	1.0	18.32
Total daytime efficiency rating						**204.79**
Dormitory	80' x .15	12.0 x .21	0 x.25	14.57	7.27	105.92
Total nighttime efficiency rating						**105.92**

Figure 16: Weninger Efficiency Rating Form

The *environmental* influences affecting turnout time include lighting and color within the facility, the noise level of a dispatch alert, fire station background noise, or items debilitating the way-finding ability of first responders such as a recently mopped floor posing a slipping hazard or an equipment item blocking the most direct path to the fire engines. These types of environmental blockades either permanent or temporary can affect turnout time by slowing the travel speeds of egressing firefighters or by detouring them to indirect travel lanes.

Birron (2016) shows that light wavelengths have key biological effects on the human body and can have both stimulating and soothing consequences on the human psyche. The type of lighting and color of lighting within a fire station may have an influence on the ability for firefighters to respond to emergencies. For example, Elliot (2014) posits that pink and orange light have a weakening effect on muscles that can slow a firefighter's ability to perform egress activities while blue light has an energizing effect. Furthermore, the human body's ability to adapt to sudden changes in light such as waking and responding to an emergency during the night can disrupt and decrease the efficiency of several body systems (Navara & Nelson, 2007). Using red light during night responses as opposed to traditional lighting may help transition firefighters from sleeping to the active state with less disruption to performance capabilities (Stevens, 2009).

The noise level and clarity of a dispatch alert also pose a possible negative influence on turnout time. An interview of 52 respondents from a county firefighter survey showed that 14 interviewees noted noise and clarity of the dispatch call to be a key indicator of reduced response time (Weninger, 2004). Mathews (1975) supports this claim and found that people reacted much quicker to audible direction when surrounding noise levels were less than 85-db. He also found that noise levels have a key influence on the attention and mood of an individual. Keeping dispatch messages clear and concise, using a notification system in a good working condition capable of delivering unobscured messages, and keeping fire station noise levels down can improve the response capability of firefighters.

Procedural considerations that may potentially influence turnout time include training levels, prior knowledge of the facility, the efficiency of donning safety equipment, and safety rules (Gwynne et al., 1999) such as disallowing running in facilities. An individual's experience with any given task has a positive relationship with performance (Quińones et al., 1995). Experience is often gained by repetitively completing tasks either in real scenarios or in realistic training scenarios (Malone, 1983). Experience is often attributed to more senior employees, but it is important to note that a mixed workforce of all experience levels has been shown to garner the best performance for an organization (Grund & Westergård-Nielsen, 2008). Continued training will build confidence and the ability for firefighters to respond to an emergency as efficiently as procedural requirements allow. Some requirements do slow down process completion though. Sometimes these requirements are wastes in the system, and sometimes they are added risk reduction steps. Safety procedures are one of the risk-reduction steps. While extremely important, they can inhibit job performance speed but increase worker happiness and satisfaction (Sackett, 2002). A workforce safety study found that 41% of workers overlook safety procedures in order to perform jobs faster (Hayes et al., 1998). Ignoring safety procedures is a counterproductive work behavior and can be more detrimental to an organization if left unchecked despite the potential speed advantage.

Behavioral concerns that may play a role in turnout time include the rate of travel speeds, reaction time to an alert, the emotional state of firefighters, and organizational decisions and norms. The rate of travel for firefighters moving from their in garrison position to an emergency vehicle during an alarm scenario can influence the speed at which the first response team can provide their services. Walking speeds vary depending on age, sex, body composition, and physical ability (Himann et al., 1988). In the U.S. 75% of firefighters are between the age of 20 and 50 and almost predominantly male ("NFPA," 2016). Bohannon shows the mean comfortable gait speed for males between the age of 20 and 50 is 4.6 ft/s and the mean maximum walking speed for the same age group to be 8.2 ft/s (Bohannon, 1997). These values will act as the travel speed distribution parameters used to determine the time needed to travel a certain distance within the model.

Research has found that humans normally do not elicit an immediate response to an alarm and spend time conducting pre-movement actions (Canter et al., 1980; Sime, 1985). Proulx (1994) discovered that this delay was not minimal and ranged greatly depending upon the type of alarm and risk associated with that alarm. He has shown that even for well trained and prepared individuals, it takes 15 seconds to begin actions associated with an alarm regardless of the alarm type. Many behavior factors played a role in determining the ability for a building occupant to egress a building in response to an alarm. Further research by Proulx found several occupant characteristics including gender, age, physical ability, familiarity with a building, past experience, training, peer and leader influences, and the emotional state of the individual egressing a building.

Scott and Myers (2005) found 5 key emotional and social contributors affiliated with a firefighter's ability to cope with work-related stress, perform as a team, and effectively execute the tasks required of them. While these behavioral factors are not directly related to facility design, they still can be used to influence the turnout time capability of a fire station. The key contributors found were:

(a) Organizational socialization played an important role in helping the firefighters learn norms of firefighter emotion management

(b) Conforming to feeling rules and emotion management norms enabled newcomers to demonstrate the extent of their assimilation

(c) The firefighters relied on organizationally-prescribed rules of emotion display to reduce uncertainty associated with assimilation

(d) The firefighters use "double-faced emotion management" (Tracy & Tracy, 1998, p. 407) which served to calm customers in emergency situations

(e) The firefighters' culture of humor helped them to cope with work-related stress and to bond with fellow firefighters.

These 5 behavioral contributors indoctrinate firefighters to both formalized rules and behavioral norms expected of them and allow firefighters to assimilate to their fire station environment (Scott & Myers, 2005). Ashforth and Humphrey (1995) suggest four methods that can allow firefighters to control and cope with the emotional aspects incumbent with the firefighting profession. These methods include neutralization, buffering, prescription, and normalization. Neutralization deters the appearance, continuation, and increase of unwanted emotion by ignoring the influence the stressor presents by "shrugging it off" or by acting as the solution to the stressor through thoughts such as "that probably hurts, but we'll take care of it." Buffering promotes compartmentalization of emotions so that they do not interfere with the task at hand. This is accomplished by focusing on the job being performed instead of the horrific scene sometimes encountered in emergency responses. Prescription includes the organizational culture and norms about how a firefighters emotion should be felt or displayed. This is done by substituting an undesired emotion with one that is in line with the organizations. These emotions are usually taught during initial training and by following the behaviors of senior team members. Normalization involves preserving the status quo of a group. Oftentimes, this is accomplished by diffusing difficult situations to a manner consistent with the organizational culture. Many times, this includes joking about a bad situation or reminding the team that they did not create the emergency situation but are there to remedy it as best as possible.

Leaders have the ability to influence and transform the behavioral norms desired within a fire station. Doing so can have positive effects on turnout time regardless of the station's design. Many organizational behavioral techniques exist to help leaders with this (Colquitt, Lepine, & Wesson, 2011; George, Jones, & Sharbrough, 1996; Hackman & Oldham, 1976; Miner, 2003). Colquitt provides one structured technique using four leadership styles; autocratic, delegative, consultative, and facilitative. Autocratic is a style where the leader makes the decision alone without asking for opinions or suggestions of the workforce. Delegative leadership gives the workforce the responsibility for making decisions within some set of specified boundary conditions. Consultative allows the leader to present a problem to employees asking for opinions and suggestions before ultimately making the final decision. Facilitative leadership seeks consensus on a solution making sure the leader's opinion garners no more merit than anyone else's opinion in the workforce. Figure 17 provides a useful guide leaders can reference when determining which leadership style will be most useful in garnering concurrence and acceptance of different decisions.

START HERE

Decision Significance	Importance of Commitment	Leader Expertise	Likelihood of Commitment	Shared Objectives	Employee Expertise	Teamwork Skills	
H	H	H	H	-	-	-	Autocratic
			L	H	H	H	Delegative
						L	Consultative
					L	-	
				L	-	-	
		L	H	H	H	H	Facilitative
						L	Consultative
					L	-	
				L	-	-	
			L	H	H	H	Facilitative
						L	Consultative
					L	-	
				L	-	-	
	L	H	-	-	-	-	Autocratic
		L	-	H	H	H	Facilitative
						L	Consultative
					L	-	
				L	-	-	
L	H	-	H	-	-	-	Autocratic
			L	-	-	H	Delegative
						L	Facilitative
	L	-	-	-	-	-	Autocratic

END HERE

Figure 17: Leadership Style Decision Guide

These four categories take into account the physical characteristics of the building, the individual agent interactions that occur between stimuli within the station's environment and the choices a person must make in response to those stimuli. Fully analyzing the configurable, procedural, environmental, and behavioral risk characteristics affecting fire station turnout time along with simulation modeling to test solutions could potentially lead to a decrease in both the variance and time for fire station turnout. Figure 18 details a list factors found in the literature that may influence turnout time.

Common Factors Found to Influence Turnout Time			
Configurational	Environmental	Procedural	Behavioral
# of Floors	Alarm Clarity	Training Level	Activity at Call
Floor Area	Lighting	Rules/ Regulations	Age
Location of Exits	Temperature	Length of Dispatch	Cultural Norms
Space Complexity	Time of Day	Equipment	Leadership
Building Shape	Station Noise Level	Type of Call	Emotions/Attitudes
Visual Access	Route Hazards	Experience	Familiarity
Building Codes			Gender
Travel Distance			Ability
Layout of Station			Limitations
Personnel Location			

Figure 18: Common Factors Found in Literature

Having first defined the research's independent variables and dependent variables, the literature review will now address the methodology used to determine the research's investigative questions.

A.3 Simulation as a Tool

Simulation is often a fundamental part of layout planning and offers the only methodology robust enough to examine the role and impact of the facility design and capture the real life issues that are often overlooked while using mathematical algorithms (Burgess et al., 1993). Simulation is often used to estimate the system parameters by contrasting different layout configurations in terms of operational parameters and to identifying potential problems and bottlenecks in proposed layouts (Ramirez-Valdivia et al., 2000). There are two main contrasting viewpoints on how simulation can be used in facility layout problems (Aleisa & Lin, 2005). The first technique is to develop a layout and then use simulation to judge its merit; the second technique is to optimize a process through simulation and then develop a layout that is compatible with the process. For facilities whose system is characterized as stochastic and complex, simulation and then layout is often recommended because it allows for the estimation of flow and accounts for the uncertainty in a forecasted end goal. In contrast, facilities that display predictable behavior with predetermined goals, such as a fire station, can elicit better gains using layout then simulate (Aleisa & Lin, 2005). Greasley (2008) showed in a case study concerning the layout of a textile manufacturing plant that discrete-event simulation is an appropriate simulation method to use in the context of layout then simulate.

Discrete-event simulation models can describe the behavior of a system through a series of events that consists of a number of entities such as people or products with associated attributes such as time in the system, resource consumption, or cost at each process step. Furthermore, it provides a method for assessing how well the system process estimates approximate true, but unknown, system behavior (Fishman, 2013). A discrete-event simulation model assumes the system being simulated only changes state at discrete points in simulated time and allows all activities within a process to be compared to the end goal of the system such as reducing time or cost (Fujimoto, 1990). This is especially useful when determining the effectiveness of a design. Inputting layout or process dependent attributes such as travel distance or time between process steps or the allowable resource allocation at each step of a proposed design will show the predicted system behavior for the systems end goal. Discrete-event simulation has become a popular and effective decision-making tool for the optimal allocation of limited resources and spaces to improve process flow and process cost (Jacobson et al., 2013).

Current discrete-event simulation modeling software also offers a visual representation of entities flowing through a process. This addition of graphical user interface is a subset of discrete-event simulation commonly known as business process simulation. This ability helps facilitate business process improvement discussions by providing a qualitative understanding of the behavior studied at a higher level than normally associated with discrete-event simulation alone (Greasley, 2008). Business process improvement efforts typically rely upon a risk framework when determining what system changes to make. Simulation has been used in many applications concerning both facility design and emergency mitigation.

A.3.1 Facility Layout Problem

Facility layout is instrumental to system productivity and efficiency (Kusiak & Heragu, 1987). The facility layout problem offers a means to improve a facility with key goals in mind by attempting to optimize the location of equipment and its functions. In general, literature pertaining to the facility layout problem revolves around production facilities focusing on the improvement of manufacturing costs, work in process, lead times, and productivity (Drira et al., 2007; Kusiak & Heragu, 1987; Meller & Gau, 1996; Yaman & Balibek, 1999). Yaman and Balibek (1999) describe it as an unstructured decision problem that may have several sub-decisions associated with it that all require different solution methods. A myriad of technique including discrete formulation, continual formulation, fuzzy formulation, multi-objective layout, and exact or approximate resolution approaches have emerged to optimize facility layout problems depending upon the specific facilities physical characteristics such as size and shape, the facilities overall objectives, and the analytical approaches desired by the problem solver

(Drira et al., 2007) but at its core, facility layout problems determine ways to quantify, evaluate, and compare different layouts through the use of performance measures related to a facility's goal. These problems are often complex and non-deterministic polynomial-time hard and do not have an optimal solution, but rather, several good solutions that a decision maker must choose from. While facility layout problems focus mainly on production and manufacturing facilities, Glenn and Vergara (2016) showed facility layout problem principles could be more diverse when they used it to plan optimal equine facility layouts.   Within non-production affiliated facilities, conducting various heuristics in search of the optimal layout is often uneconomical and therefore rarely done (Drira et al., 2007). An issue with the facility layout problem is it assumes the facility goal is the most important design factor (Raman, Nagalingam, & Lin, 2009). To combat this issue, simulation has become a common theme throughout facility layout problems to both measure the effectiveness of designs developed under other methods and to aid in process improvement efforts within pre-established and alternative layouts meeting the desired user constraints (Liggett, 2000).

A.3.2 Past Uses Of Simulation in Emergency Response

Emergency planners and responders often use simulation for a myriad of problems. Simulation is used in route optimization to decrease the likelihood of negative outcomes and to increase the efficiencies of travel to an emergency. It is used to ensure the de-confliction of vehicle and pedestrian routes in high traffic areas of urban environments. Notably, in 2015 during the Muslim observation of Ramadan, nearly 700 visitors were killed in an unintentional stampede. The city of Mecca, where Ramadan is held, sees population increases of nearly 40% or 14 million each year. This rapid population increase along with the religious rituals the visitors perform has caused numerous crowd disasters culminating in several hundreds of deaths prior to the use of crowd control measures established after the 2015 disaster (Müller, 2015). The use of simulation models has allowed the city to direct guides charged with leading small groups through the various ceremonies intrinsic to Ramadan on what paths and timelines to follow. It has also allowed emergency planners to pinpoint critical risk nodes created by the architecture of the city and mitigate against them. These actions have reduced the crowd disaster incidents drastically (Müller, 2015; Sarmady, Haron, & Talib, 2007). Similarly, fire emergency service professionals use route optimization to pre-determine the most time efficient and conflict-free path to an emergency. Such actions allow firefighters to become familiar with the route to different areas of their respective response zones and pre-disposes them to paths with higher likelihoods of constraint-free travel lanes (Needham, Anundson, Smith, & Goschen, 2007). Models intending to improve movement and efficiencies through smaller systems are also used profusely.

Within the confines of a building system, emergency preparedness modeling has been used to determine the rate at which building inhabitants can evacuate a facility and how well first responders can navigate an unknown space. Evacuation is a topic that has been studied for several decades which have led to seven common approaches for determining the time needed for a population to exit a facility (Zheng, Zhong, & Liu, 2009). Several simulation models using combinations of these methodologies exist to aid in this endeavor. The evacuation time can then be used to determine the validity of the design of a building with regards to evacuation standards and determine if additional exits or pathways are needed.

Opposite of evacuating a building, entering a building is also commonly studied. The need for emergency first responders to rapidly and efficiently conduct search and rescue efforts gives rise to research into real-time modeling tools for route analysis within buildings. One such method uses 3D spatial information along with smoke movement analysis to provide the quickest safe route within a facility to guide firefighters through unknown building environments (Wu & Chen, 2012). This capability, via the use of a heads-up display in the firefighters mask, allows rescue personnel to both search buildings efficiently and direct threat free evacuation routes.

Simulation in building design has not been confined to route optimization and evacuation efforts alone. Currently, different models are used to optimize facility systems through the use of building performance-based research. This research uses the building design and offers potentially relevant design information for state of the art Heating, Ventilation, and Air Conditioning systems, plumbing systems, and electrical systems solutions along with a multitude of additional system performance areas (Hopfe & Hensen, 2011). The goal of these simulation models is to optimize the cost effectiveness and user comfort. In addition to system performance, simulation modeling has been used to allocate resources and improve flow through a facility properly. These performance simulation methods may present solutions at odds with an optimized turnout time design layout, and decision makers will need to determine which is more valuable to the organization. Health care facilities have become a prime target for the use of discrete-event-simulation models to increase patient flow while minimizing costs and improving the level of care provided (Jun et al., 1999). This simulation has helped design medical facilities to enhance the ability of doctors and patients to efficiently move from different rooms and units within the hospital which have effectively decreased the time to receive care and the overall time patients spend in the facility when performing routine health and preventative care checkups.

Reliability analysis is also used in emergency management simulation applications. Reliability analysis is concerned with determining a system's overall failure potential based on the failure probabilities of the components of the system (Robert E. Melchers, 1999). Jackson (2011) proposes the use of this analysis to determine response reliability or the likelihood that a response system will be able to meet or exceed the capabilities for which it is intended in future incidents. He used this method to determine the probability that a natural disaster response team would successfully complete all search operations within a specified period. This was accomplished using a static Monte-Carlo Simulation that combined the probability of occurrence and consequence of an occurrence for several potential failures typical of search operations. Using reliability analysis for capability predictions can aid decision makers in determining resource levels, plans and policies, and process flows by predicting actual system performance in error prone environments rather than using perfect condition measures (Billinton & Wangdee, 2006). An issue with reliability analysis, however, is its accuracy depends on identifying a large percentage of the failure possibilities within a system and accurately capturing the effects those failures can have on the system.

Simulation gives a tool to repetitively conduct experimental trials for events that occur rarely or within systems that, even under the most controlled conditions, produce varied results. Simulation also gives engineers a means to test building designs without full-scale demonstrations to show the effects different proposals may have in regards to adherence to prescriptive building codes and the rigid regulations held within them. Furthermore, simulation offers a structured avenue to test potential solutions where actual implementation is costly or difficult during the solution development stage. Simulation is not the only modeling type to offer a framework for solving problems; risk assessment models also provide an important framework.

A.3.3 Risk Assessment

Risk assessment models are used to determine potential risk factors and provide a systematic approach to developing mitigating solutions. In general, risk has been defined as a measure of the probability, the severity, and the exposure of all hazards of an activity. Currently, risk analysis is performed in numerous ways depending on the person performing the analysis and the customers requesting it. Failure modes effects analysis is perhaps the most advantageous risk model because it accounts for the hazards that may cause individual components to fail as well as the overall system design to fail (Jackson et al., 2011). Faber mirrors the belief that using Failure Mode Effects Analysis is a good way to identify hazards across all disciplines, but goes on to say that facility design professionals rarely use this tool when constructing new buildings (Faber & Stewart, 2003). It follows four steps aiming to decrease the overall risk to a system and to mitigate biased decision making which could lead to unacceptably high consequences to people, the environment, and to the facility.

The first step in this failure mode effect analysis framework is to map the system. This step consists of having a thorough knowledge of how an organization operates. Many owners will already have a deep familiarity with their organization and be able to communicate how their particular processes and procedures work effectively. Very rarely are new buildings constructed for an owner who does not know the intent the facility is going to serve, the different entities that will occupy and function within that building, and what those functions need to operate effectively. Faber (2003) shows that logic trees and cause and consequence charts are a useful and effective way of communicating the processes within a facility to those who are not affiliated or aware of how the process should occur. Logic tree analysis includes identifying sources of risk in an engineering system and analyzing them with respect to their chronological and causal components and is mainly used with structural system development by taking into account the effect of dependency between events that could lead to failure (Ditlevsen & Madsen, 1996). For example, the owner of a hospital will be able to map out how the different function within a building interact with their own function as well as how they are intertwined and operate with entities of different units within the hospital. Logic trees can be used to show these interactions and how an organization as a whole operates together. By incorporating different entities in the most logical manner in the design process with flow and efficiency maximized, the facility will operate closer to the owner's ideal scenario maximizing both function and satisfaction.

The second step is to identify potential hazards within the facility. This usually occurs by looking at prior incidents that have proved to be detrimental to the facility itself or to the function the facility is to serve. This step looks to find specific ways in which different parts of the system, be it the HVAC system, the door locking mechanisms, the interaction between the loading dock and the kitchen in a restaurant, or the travel distance in a hospital could break down and degrade the performance the facility is meant to serve. It uses these uncertainties to understand the risk potential several designs may encounter.

This step can use probabilistic, past occurrence, knowledge-based, and possibilistic approaches either individually or collectively to finding hazards. Possibilistic approaches concern thinking in a "what if" and "worst case scenario" mind frame by imagining all the ways something could go wrong (Clarke, 2006). The use of several approaches can help identify and plan for the risks posed by natural disasters, normal accidents (those posed by system or process failures), and abnormal accidents (those induced by evil design) (Mitroff & Alpaslan, 2003). Uncertainty analysis in civil engineering is used profusely in landslide, bridge, and waterway design efforts to minimize the potential of catastrophic failure (Dai, Lee, & Ngai, 2002; Yanmaz, 2000).

Once hazards have been identified, the third step in this process is to assess the probability of the failure occurring. Faber and Stewart (2003) contests that the probability or uncertainty of an event occurring can be categorized into aleatory or type one uncertainty which is the natural variability of an event itself, epistemological or type 2 uncertainty which consists of modelling uncertainty and how relationships between factors affect the system, and lastly statistical uncertainty using previous failure information. Past data will usually provide the most accurate statistical relevance for an event if the hazard often occurs (Bertolini, Bevilacqua, & Massini, 2006). However, when determining the probability of the less known hazards, the reliability and expertise of subjective judgments given by those with the knowledge of such occurrences is perhaps the best option (Linstone & Turoff, 1975). To further enhance the credibility of these judgments, peer reviews have been conducted to decrease the uncertainty of the probability proposed. The ability to most accurately depict the actual probability of a risk occurring will affect the ability of the analysis to provide precise quantification.

The fourth step in failure mode effects analysis is to determine the severity of the hazard. This is generally measured in terms of the amount of detriment caused, be it the loss of money, environmental deterioration, loss of life, or loss any other kind of damage. One technique to evaluate this is to use prior analysis. This technique couples with decision tree analysis and uses a formula that takes into account where on the decision tree the failure could occur, what type of hazard it is, the probability of that hazard occurring, and the chain of events the failure could cause (Ericson & Ll, 1999). One of the difficulties of this step is comparing the direct economic losses such as the loss of productivity, or the cost of rebuilding a damaged facility, to human losses such as death or injury, to the indirect losses such as unemployment, inconvenience, or the possibility of economic growth (Rice & Cooper, 1967). Finding a common denominator for these different kinds of losses is often left as a decision point for the owner.

Once the severity and probability of a potential risk have been found, the design entity of the construction process can use analysis that combines these two factors and rank them in order from most critical to least. That list can then be categorized into acceptable risk, unacceptable risk, and a middle region between the two in which the owner must decide the course of action (Melchers, 2001). In doing so, failure modes effects analysis provides a consistent and worthwhile tool to recognize and mitigate risk factors.

By intertwining simulation and risk assessment while focusing on the configurable, procedural, behavioral, and environmental risk factors shown to be significant in facility performance, the ability to both measure the effectiveness of a facility to aid in the completion of a goal and to recognize and mitigate performance issues may be possible. The use of this approach with the intention of aiding emergency response facilities such as fire stations has not been a focus of literature, but its use may provide significant emergency response improvements.

Appendix B. Methodology

Executive Summary

A time-and-motion study was conducted at the sample fire station. Task times of the activities were fit to probability distributions and incorporated into a baseline simulation model created with Rockwell's ARENA software. The baseline model was then validated by comparing simulated response times to historical data. After validation, alternative models with specific system modifications were built incorporating procedural, environmental, behavioral, and configuration changes to the system. Each model was simulated 300 times showing the fire station's likelihood of meeting the two-minute guideline. Furthermore, the baseline model was measured against 9 fire stations changing only layout parameters to determine its use as a design tool.

B.1 Introduction

The steps outlined in this chapter describe the methodology followed when determining the investigative questions. An action research based approach was taken to both provide an example of practices used to conduct this research and to test if the discrete-event simulation approach is a useful tool in the context of facility design. Furthermore, this approach was used to discover if turn-out time process improvement suggestions based on key factors is feasible. The author of this research acted in an observatory role and carried out both the process of the study and all it entails as well as constructed the discrete-event simulation model. Collection of data to include process durations, task allocations, and process relationships for the study were completed by the author in tandem with and by observation of employees of the case study fire station in order to construct the simulation model used in the analysis. While limitations exist when creating a model based on a single-site study, the model was validated against 9 independent fire stations to ascertain its value as a decision tool for fire station design.

This chapter will detail the turn out time system description, the data collection description, assumptions, task network descriptions, validation approach, and the experimental design and alternative model creation approach.

B.2 System Description

The first step in the methodology is to represent the turn-out time events taking place at the case study fire stations as discrete steps. Natural breaks presented themselves in the process making partitioning of the timed events easy to discern. The following eight steps describe the flow of events currently completed by firefighters to dispatch and egress the case study fire station.

Step 1: Phone Rings In Dispatch Center And Dispatcher Answers The Phone

During this step at least one dispatcher is needed to answer the phone. Once the phone has been answered the dispatcher will collect pertinent information from the individual making the distress call and classify it as either a medical, structural, or airfield emergency. The time needed to complete this task is determined by the speed the dispatcher can garner information from the caller and record the information given. The input to begin this step is an emergency phone call. The resources needed consist of a single dispatcher and a dispatch center. The outputs for this independent variable will be the time it takes to receive, understand, and record a call and to correctly dispatch firefighters and alert them to the call type.

Step 2: Dispatcher Initiates Call (Medical, Structural, Airfield) Over Intercom

During this step, at least one dispatcher must operate the dispatch equipment that sends a message to all firefighters within the fire station. The information relayed includes what type of call it is, where the emergency is, any pertinent factors specific to the emergency, and when the emergency began. This step is started as soon as the dispatcher finishes the emergency phone call. To complete this step one dispatcher is needed and the output consists of the time it takes to formulate a dispatch message, operate the station intercom equipment, and the time it takes to deliver the message.

Step 3: Firefighters Stop Current Activity

During this step, firefighters are mixed into different rooms within the fire station. They all have a pre-assigned role telling them what order of call they will take, and what type of call they will be responsible for responding to. When the dispatch call comes over the intercom system, all firefighters stop their current activity and perform pre-movement actions such as logging out of a computer, turning off an oven, waking up, or getting off of fitness equipment such as a treadmill. This step takes anywhere from 2 to 8 firefighters all acting independently of one another, and the output consists of the time it takes each firefighter to perform the pre-movement activities associated with the room they currently occupy.

Step 4: 2-8 Firefighters Travel To Fire Engine In Station Bay

During this step, the firefighters need to egress the specific room they are currently in and then decide what the most direct route to the station bay is. They then need to travel to the station bay as quickly as possible without violating any rules such as no running and then travel to the specific fire engine needed. The output of this step is the time it takes for each dispatched firefighter to travel to the fire engine from their pre-emergency location.

Step 5: 2-8 Firefighters Open Garage Door

During this step, the firefighters must enter the bay and travel to the designated fire engine. Once there, they need to determine if the garage door is open or if it needs to be opened. If it is open, they will proceed to the next step. If it is not, then the first firefighter to enter the bay will walk to the garage door opening button and open the garage door before proceeding to the next step. The output of this step is the total time it takes the firefighter to open the garage door, and the time it takes for the garage door to open fully.

Step 6: 2-8 Firefighters Don Equipment

During this step, the firefighters will don all protective equipment based on the call type. This equipment includes bunker gear, self-contained breathing apparatus, helmets, and many other safety gear. This output will consist of the total time it takes the firefighters to don the correct safety gear based upon the call type.

Step 7: Conduct Pre-Movement Protocol

During this step, the firefighters, depending upon their pre-determined role, will execute pre-movement operations such as inspecting the fire engine, disconnecting the air hose from the fire engine, starting the fire engine, inputting directions into the GPS system, putting on seat belts. The output will consist of the time it takes for each firefighter to complete the procedures of the role they were preassigned and to get into the fire engine.

Step 8: Fire Engine Departs Station

During this step, the driver of the fire engine will determine if all Firefighters have proper equipment donned and all pre-movement protocols complete. Once the driver has determined this, the driver will depart the fire station. The output of this step will be the total time it takes for the driver to determine if the vehicle is ready to depart and the time it takes for the engine to leave the station fully.

The total turn-out-time will be the sum of the largest time it takes for each step to reach completion.

B.3 Data Description

Input Data Requirement	**Information Needed**	**Description**
Step 1. Phone Rings in Dispatch Center	1. Average percent of calls by Call Type	The case study fire station dispatch center collects and keeps detailed logs of the call type made each day in accordance with NFPA accreditation requirements.
Step 2. Dispatcher Initiates Call over Intercom	1. Time to collect call information and relay the message over the intercom system	The case study fire station dispatch center collects and keeps detailed logs of the call type made each day in accordance with NFPA accreditation requirements.

Step 3. Firefighters stop current activity	1. Time to conduct pre-movement activities depending upon the room they occupy at time of call 2. Average occupancy rate of all rooms	For this step, the author gathered data using a stopwatch that details the distribution of how long it takes a firefighter to stop the current activity they are doing and egress from their current room to the hallway of the fire station. Each room will have different activities associated with it that may take longer than others (Gym-may need to get off of work out equipment, Dorm-may need to wake up, training room- may need to log off a computer, kitchen-may need to turn appliances off, etc.). The author will also find what rooms are occupied most frequently throughout the day to appropriately model where at in the station a firefighter is most likely to be.
Step 4. Firefighters travel to fire engine in station bay	1. Average distance from rooms to center of vehicle bay 2. Average walking speed of fit adult	The author measured the distance from each room to the center of the bay using accurate as-built building blueprints with a distance scale and using walking speeds of a fit individual representative of a firefighter to calculate the time distribution needed to travel

		the distance. The author verified this with time motion analysis data of actual firefighter movement.
Step 5. Firefighters Open Garage door	1. Time to push garage door button 2. Time for garage door to fully open 3. Average percent of time garage door is open prior to a call being received	The author used a stopwatch to measure the distribution of time needed for a fire fighter to complete the actions needed to open the garage door and the time taken for the garage door to fully open. There were several garage doors, and each was measured to determine if a statistical difference in opening time existed; all garage doors were found to open at a similar rate. The author surveyed employees to determine the probability that the garage doors are either open or closed prior to receiving an emergency call.
Step 6. Firefighters Don Equipment	1. Time to don each type of fire equipment	The author used a stopwatch to determine a distribution of how long it takes firefighters to don different types of required fire equipment associated with the call type
Step 7. Firefighters	1. Time to complete pre-movement	The author used a stopwatch to determine the distribution of how long it takes

conduct pre-movement protocol	protocol	for each firefighter to complete the actions needed by job type (driver, navigator, passenger) and call type.
Step 8. Fire Engine departs station	1. Time it takes for fire engine to drive out of the fire station fully	The author used a stopwatch to determine the distribution of how long it takes for the fire engine to depart the station.

B.4 Model Assumptions

A number of assumptions were made when building the model. These assumptions are described in detail in this section.

Assumption #1:

Only one response can be run at a single time and simultaneous responses will not occur.

The purpose of this study is not to determine needed resource and staffing levels at fire departments. To that end, it is assumed that each model simulation run is independent of the next. Furthermore, it was found that real world calls at WPAFB Fire Station #1 very rarely overlapped and that there would be no benefit of running simultaneous calls within the model. Additionally, within the ARENA model, running more than one response at a time will affect the coding of the model and give incorrect results.

Assumption #2:

Assume subject matter expert inputs are correct.

Due to limited real world calls conducted by the WPAFB Fire Station #1, experts were interviewed to provide further insight to the turn-out time process and data needed to develop a model. The subject matter experts consisted of both veteran administrative supervisors and mid-level firefighters who have been engrained within WPAFB Fire Station #1 for years. Their experience and knowledge of the daily actions conducted at the fire station qualify them as reliable individuals to interview. The information garnered from these individuals was validated by the author through measuring the limited real world call data and through turn-out time practice runs. The compilation of information collected from interviewing the subject matter experts was assumed to be accurate for all areas.

Assumption #3:

Flow of processes conducted will not change.

If the flow of the turnout time processes changes from the model flow, then the model will be rendered obsolete and not represent the current system or be useful in determining improvement recommendations.

Assumption #4:

Assume there will be no failures in the system.

A failure in the model will render false results and skew the validity of the model. A failure could include an alarm system malfunction, broken equipment items, or any failure that is not normal to the usual turn out time process.

B.5 Task Network and Description

This models intent is to mirror the turn-out-time processes of Fire Station #1 at WPAFB to determine the processes most detrimental to dispatch and firefighter egress guidelines. The model does this by breaking the processes into several distinct steps and covers the entire range of scenarios the firefighters may face when egressing from the station. A triangular distribution was used for all model inputs. This distribution type is recommended by many when limited data is available (Altiok & Melamed, 2001; Banks, CARSON II, & Barry, 2005; Kelton, 2002) even though it does not fully represent the actual process variations within a system. Furthermore, the triangular distribution is generally used when building the first stage of a model where a basic understanding of the system is being developed. It is important to note, that using the triangular distribution instead of the normal distribution will give simulated results with less variability than is seen in actual turnout processes. The model begins when the emergency response phone rings in the dispatch center. The first process immediately follows this and measures the time it takes a dispatcher to answer the phone, communicate with the caller, and to collect and record all information pertinent to the emergency. Detailed records of this step exist and show that these calls last anywhere from 10 to 65 seconds with the mean at 25 seconds. The model then measures the time it takes for the dispatcher to relay the emergency message to the fire station. This follows a normal distribution and lasts anywhere from 5 to 15 seconds.

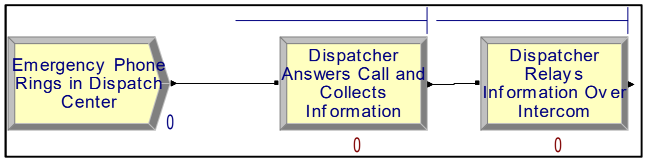


Figure 19: ARENA Dispatch

After these steps the model transitions from the dispatch portion of turnout time and focuses on the egress portion. The models first step in this is to pre-determine if the garage door the firefighters will leave from s open or not. Subject matter expert interviews show that 35% of all calls will have the door previously open. Once the verdict of if the door is open or not is decided the model assigns the door as open or as closed and if open, assigns the firefighters to a door open egress procedure that skips opening the garage door.

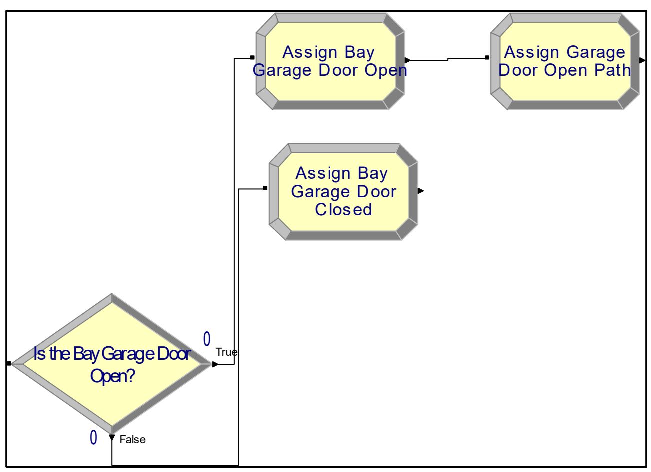


Figure 20: ARENA Garage

Next, the model determines the emergency call type. Numerous and detailed data exists and shows that 41% of calls are medical, 57% are structural, and 2% are airfield calls. After the call type is determined, the model dedicates one driver and one navigator to medical calls, one driver, one navigator, and two passengers to structural calls, and one driver, one navigator, and six passengers to an airfield call. Each of these simulated firefighters will then act independently of the next throughout the remainder of the model and will not act as a single unit again until all firefighters are in the fire engine and departing the station.

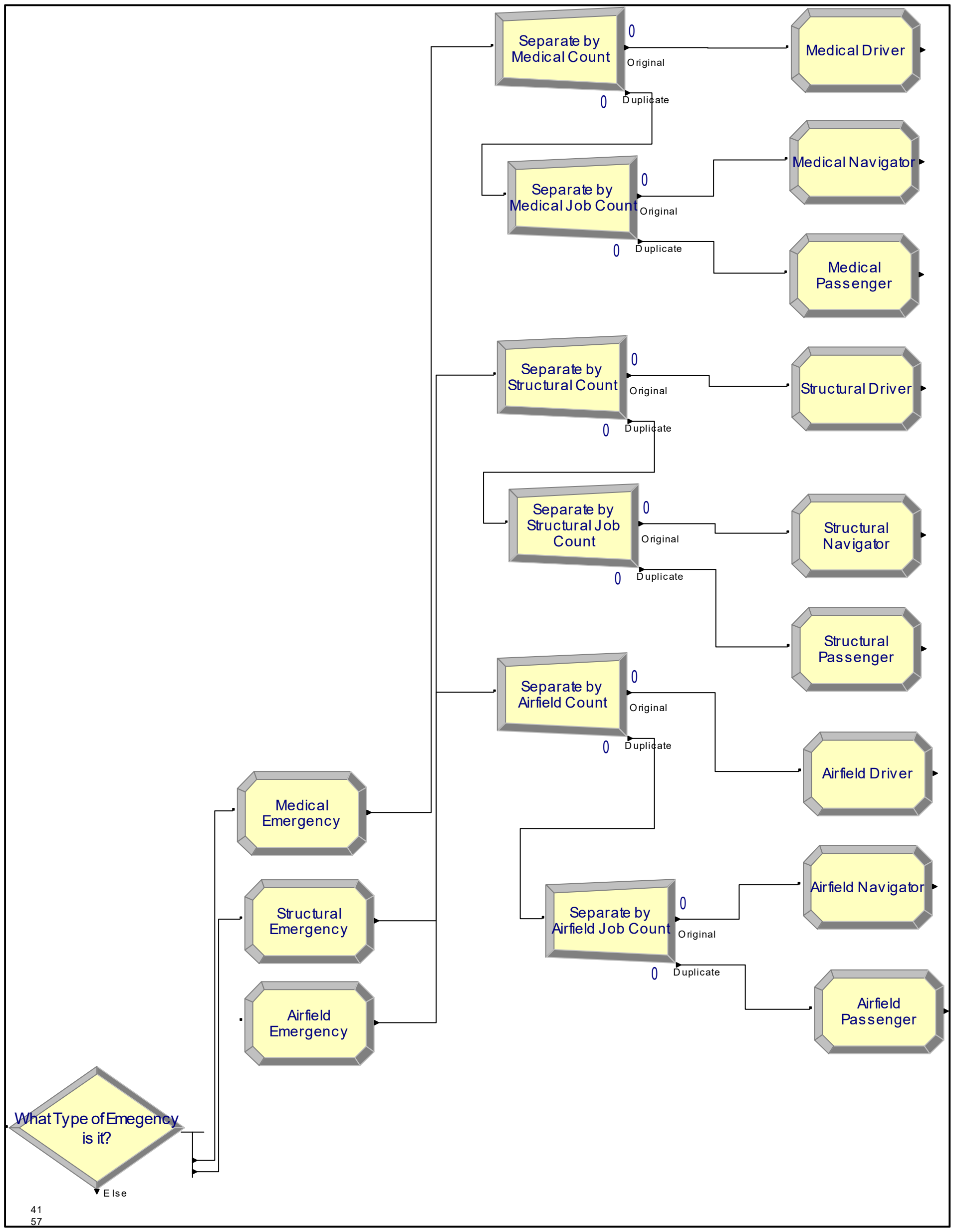


Figure 21: ARENA Job Assignment

After separating firefighters by call type, each firefighter is then assigned to be in one of eight possible locations within the fire station. Those rooms are the dorms, kitchen, restroom/shower, recreation room, gym, training room, garage bay, or in an administrative office. The decision of what room each firefighter is in is based upon room occupancy rates gathered from subject matter expert interviews. Each room will then have an associated pre-movement time that includes the time to turn off cooking appliances, finish in the restroom, log-off a computer, and many other activities the firefighters must finish before exiting the room. Each room will also have an associated travel time from that room to the fire engine. These times are calculated using the average walking speed of an athletic adult male multiplied first by the closest point to the fire engine and then again from the furthest point in the room to the fire station to give a range for the travel.

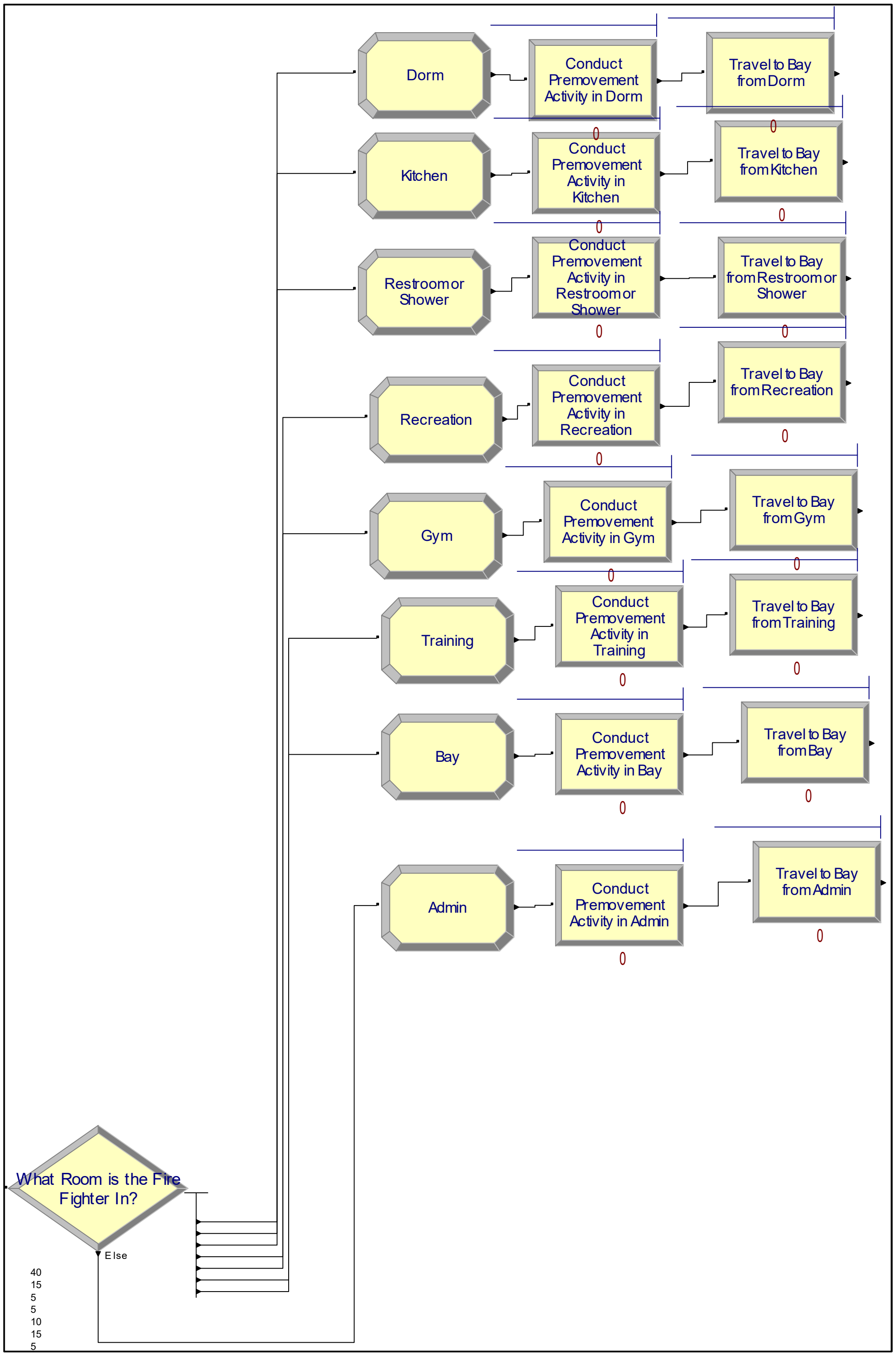


Figure 22: ARENA Room Assignment and Activities

From here, the firefighters can take one of three paths consisting of a normal pattern of procedure with some differences for each path. The normal procedures include donning the equipment needed for the call type and conducting pre-vehicle movement and inspection actions. The duration of each of these steps was collected using subject matter expert interviews. If the garage door was deemed closed then the first firefighter to get to the bay will be responsible for opening the garage door and will take the path with the extra step of opening the garage before returning to normal procedures. As the first firefighter is completing the normal procedures, the garage door will simultaneously open. These firefighters cannot enter the fire engine until the garage is fully open. The second path is if the garage door is deemed closed, but the firefighter is not the first to arrive at the fire station. This firefighter will complete the normal procedures with no added steps. The third step is if the garage door is deemed already open then all firefighters will complete the normal procedures with no added steps. The last step is to depart the fire station. This cannot occur until all firefighters have completed each prior procedure assigned.

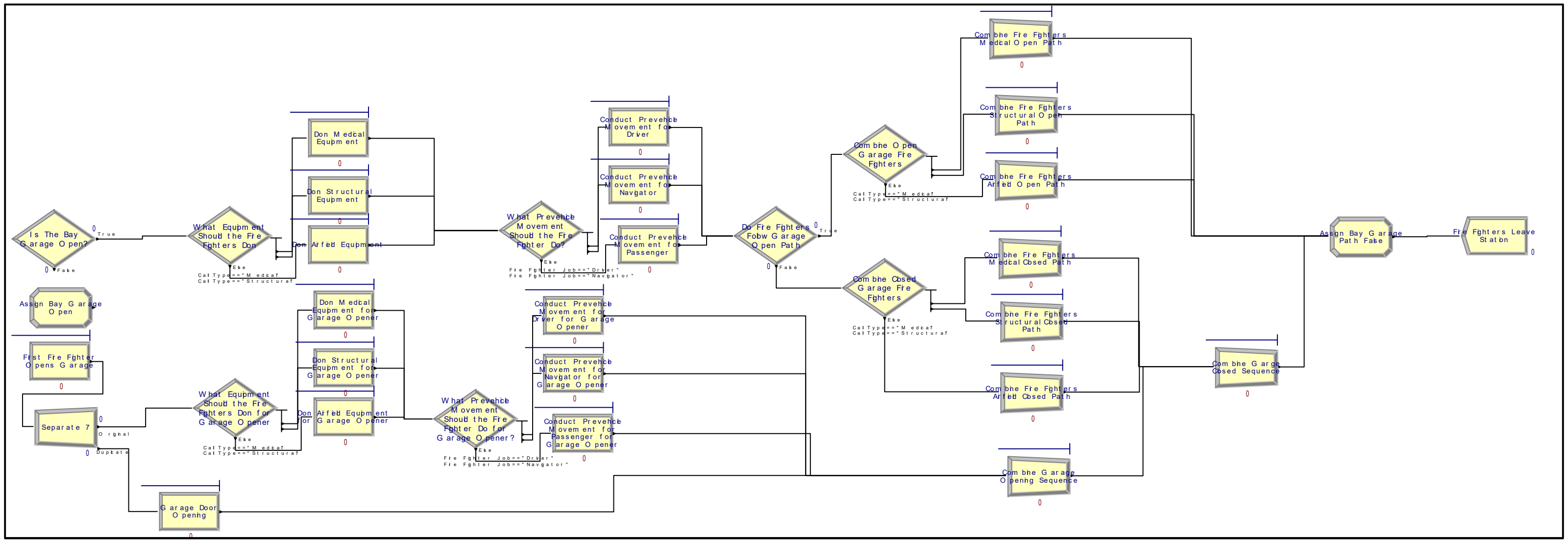


Figure 23: ARENA Firefighter Movement Activity

This model is designed to run each call independently of the next. When the model is run 300 times, the fastest turn-out-time was 1.35 minutes, the slowest was 3.06 minutes, and the average was 2.31 minutes. The processes with the most influence on turn-out-time were donning equipment, answering and collecting information from the emergency call, opening the garage, and travel time to the garage bay.

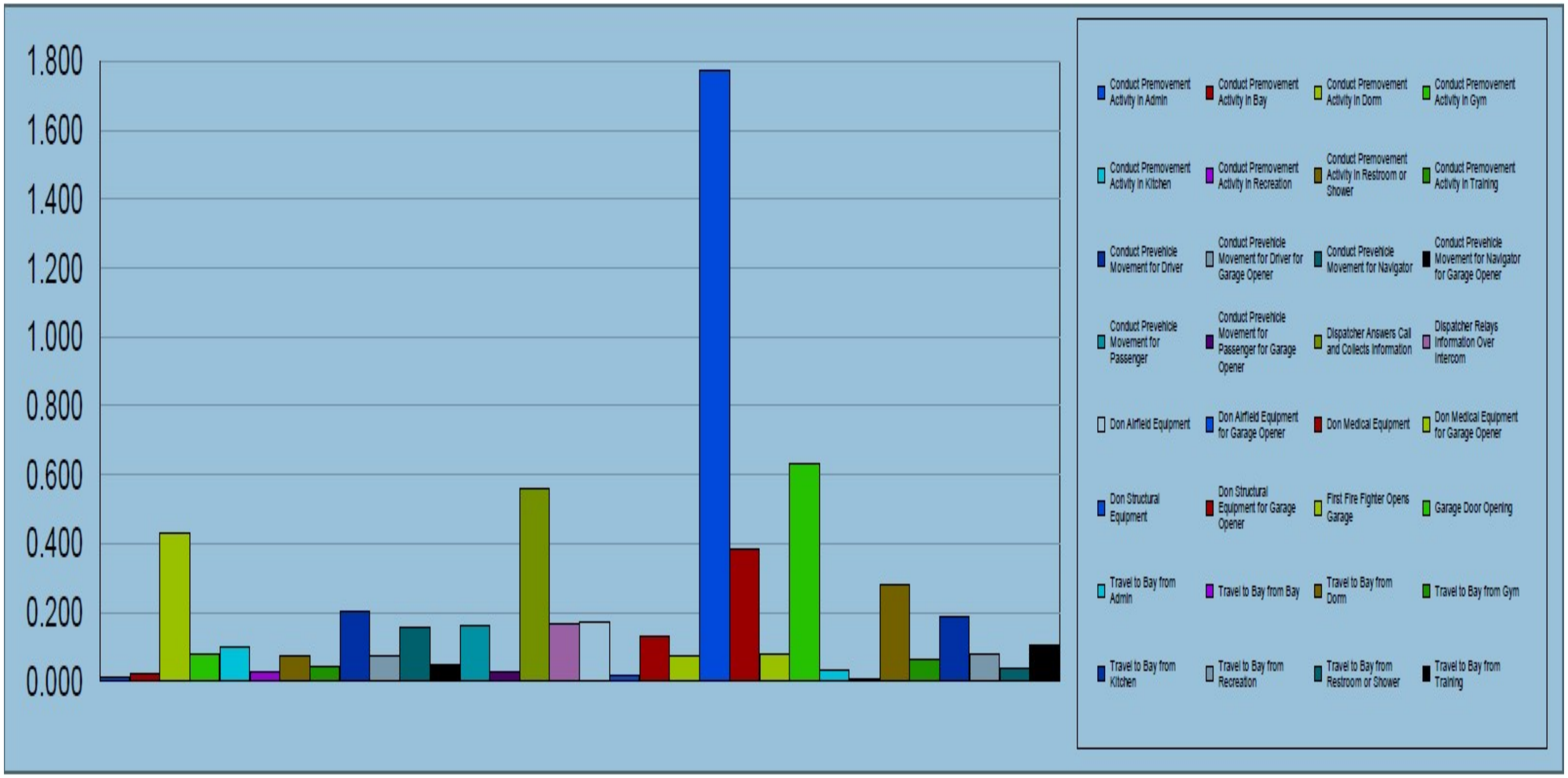


Figure 24: ARENA Activity Time Output

This information will be useful when determining what steps to look more closely at for time-saving factors. Overall, this model mimics the turn-out-time activities of Fire Station #1 at WPAFB and is useful in determining what factors contribute most to the overall dispatch and egress times.

B.6 Validation

The response variable being validated is the total turn-out-time. Turn-out-time includes the total time it takes to complete all steps involved with an emergency response from the time the phone begins to ring in the dispatch center notifying the station of a potential emergency to the time it takes the fire engine to leave the station completely. Travel time to the emergency and time to provide care is not included. Currently, the dispatch center at case study fire station collects and keeps detailed logs of every emergency call received and the turn-out-times included for each real world call. I was provided turn-out-time data for the past four years. While some test runs were recorded as well as a minimal number of outliers skewing the data, a quick data scrub of those erroneous points provided an in-depth look at the real world turn-out-times of the case study fire station. The ARENA model also provides total turn-out-time data for 300 runs. This data is based on the inputs for each process needed to complete the actions necessary to exit the fire station and used discrete-event simulation to provide a range of values. These values will be compared to the real world data using confidence intervals and a t-test to validate its ability to predict the stations turn-out-time. The number of runs was decided by determining the minimum run number to save in simulation time while still collecting the full range of results. It was found that more than 300 runs did not provide additional clarity to the turnout process while less than 300 runs resulted in missed information. In applied practice, confidence intervals are typically stated at the 95% confidence level and will be used for this validation.

	Actual Data	Simulation Data
Mean	2.33	2.31
Standard Deviation	0.63	0.33
Number	482	300
Confidence	1.96	1.96
Max	3.50	3.06
Min	1.25	1.35
Range	2.25	1.71
Upper Bound	2.39	2.34
Lower Bound	2.27	2.27
Overall T-Test	0.59	

Figure 25: Baseline Model Validation Results

The confidence interval for real world data is 2.27-2.39 minutes and 2.27-2.34 minutes for the simulated data. The t-test provided a value of 0.59 showing that the simulation is able to predict the stations turn out time due to the fact that the confidence intervals overlap and that we fail to reject the null hypothesis. For this reason, I conclude that my model needs no further changes and that an iterative calibration is not needed to make the model more realistic. However, this model does not capture the full range of turn-out-times seen in the actuality. If more time were available, more data collection on process times would be collected and potentially alleviate this issue and provide model more in line with the real world. All values and data points for both real world responses and simulated responses can be seen on the following pages.

B.7 Experimental Design and Alternative Model Description

The first change my alternative model will implement is the ability for the dispatch center to open the garage door via the dispatch center when the call first comes in. This will eliminate the need for the first firefighter to spend time opening the garage and will vastly reduce the likelihood that the garage door is the factor inhibiting the fire truck from leaving the station. To accommodate this change, the model will variate from Figure 26 to Figure 27 by reassigning the garage opening duties to the dispatcher. In the initial model, when the dispatcher is finished relaying an emergency message the responsibilities of the dispatcher end. In the changed model, the dispatcher's responsibilities continue after initiating a call and the new responsibilities run in tandem with the firefighter's responsibilities via a Separate command in ARENA. This command delineates the actions firefighters must accomplish and actions the dispatcher must accomplish. This change will also eliminate duplicate paths on the end of the model streamlining both the model and the actions the firefighters must accomplish. It eliminates the need to know if the garage door is either open or closed and deems the garage door irrelevant to affecting turnout time.

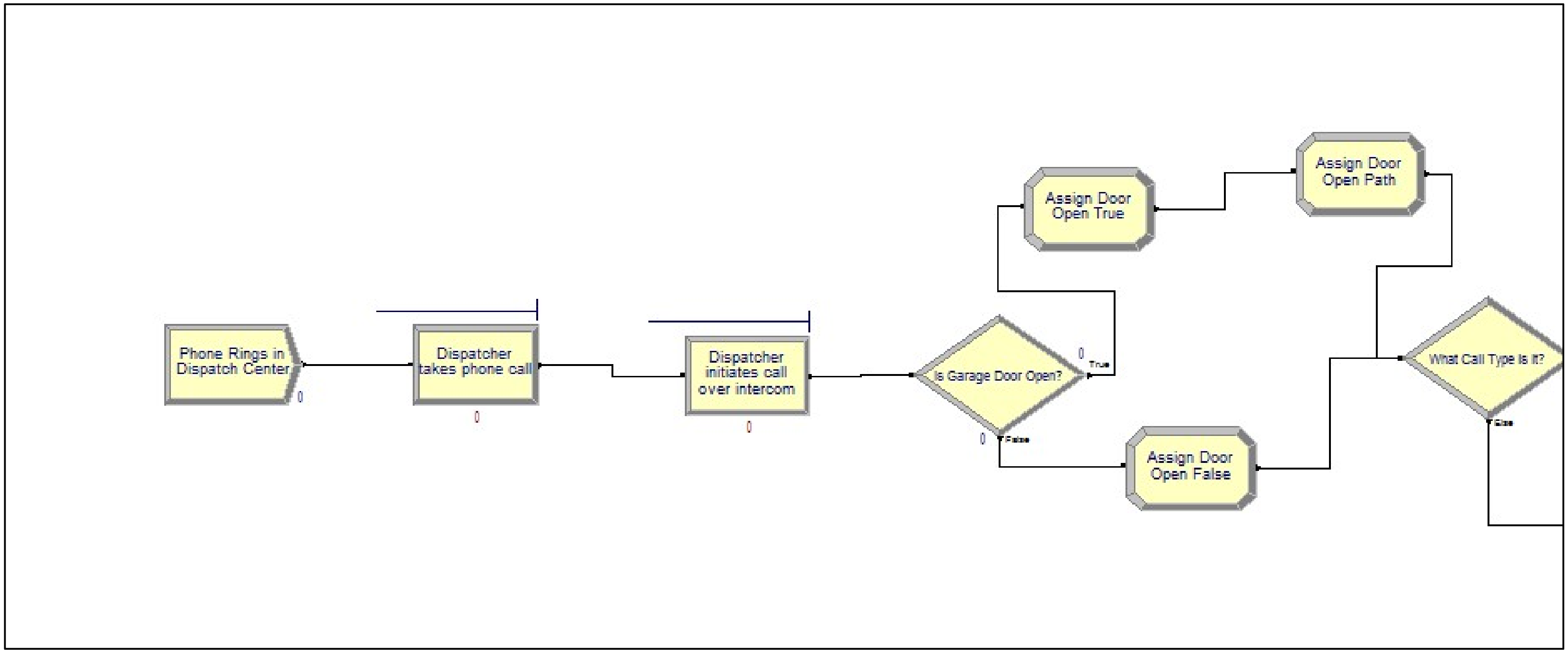


Figure 26: ARENA Alternative Model #1 Initial

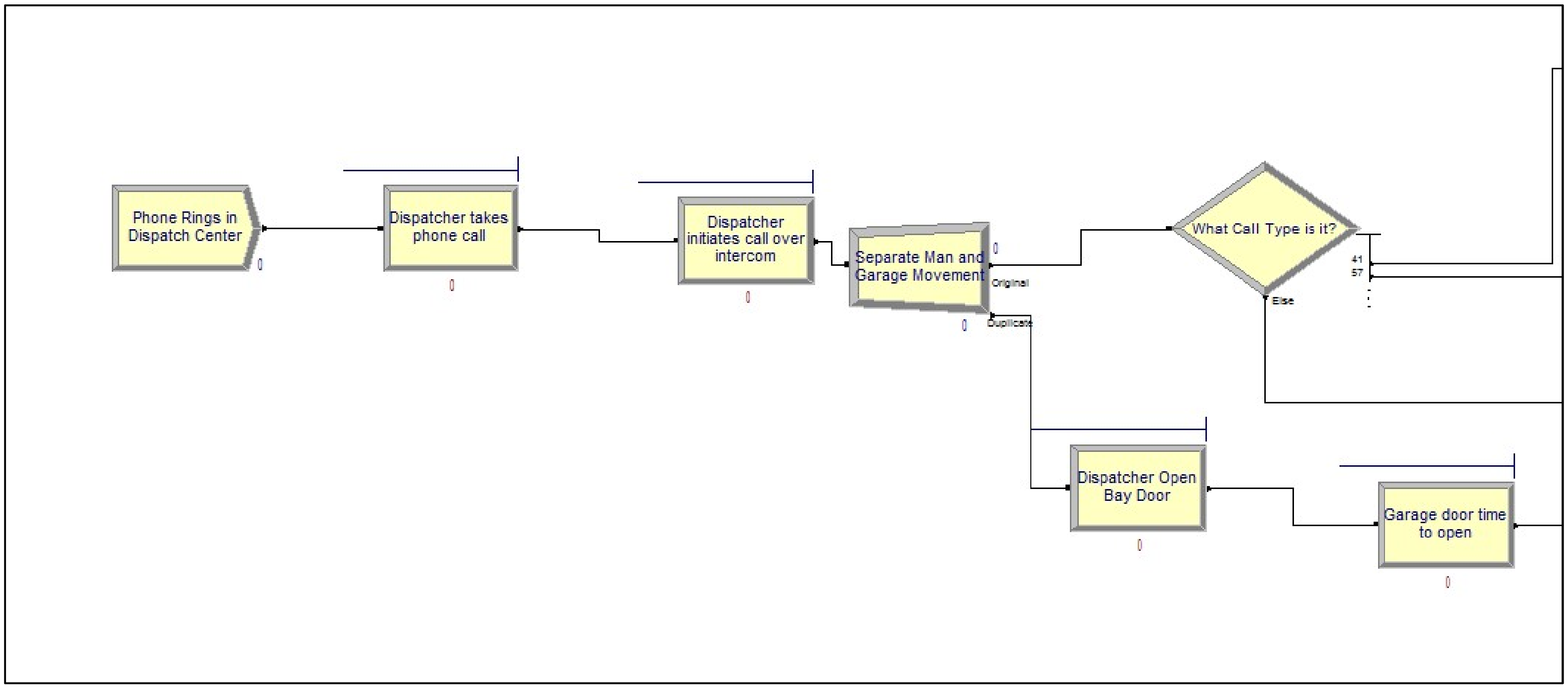


Figure 27: ARENA Alternative Model #1 Change

The second change the model will implement is giving the dispatch center the ability to pre-warn firefighters of an impending call. This will occur by giving the dispatcher the ability to press a medical, structural, or airfield button on their control center once they discover the category of emergency while still talking to the person calling in the emergency. The button will cause an alarm of some sort (certain pattern of flashing lights, voice recording, electronic signs in every room, etc.) that will allow the firefighter to know the category of call and respond accordingly. The remainder of the information the dispatcher collects will be transmitted via the intercom system or radios once the dispatcher has ended the call. This will give the firefighters a head start on their egress procedures allowing for a faster turn-out-time. This change will occur in the model by adding a Separate command in ARENA after the dispatcher answers the phone. The model is then aligned by either dispatch duties or firefighter duties. This change allows firefighters to react to an alarm with a head start from normal procedures.

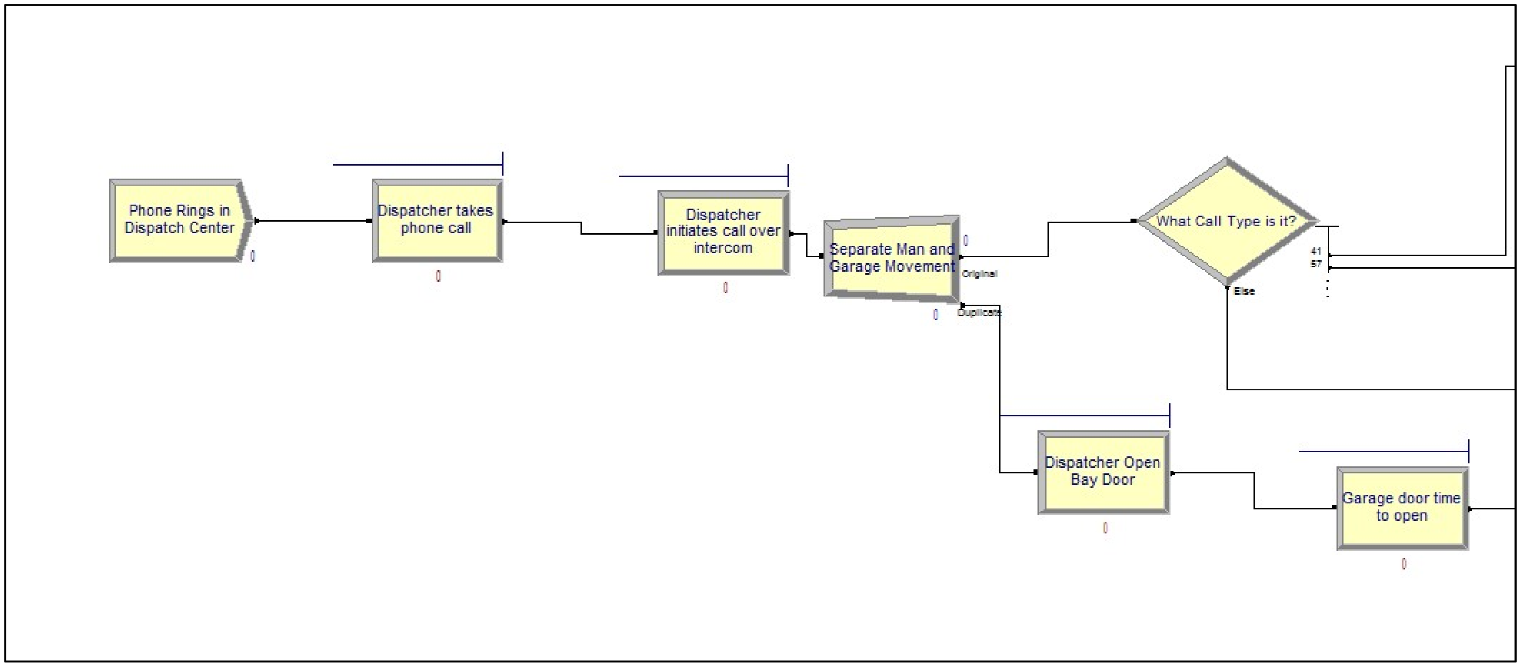


Figure 28: ARENA Alternative Model #2 Initial

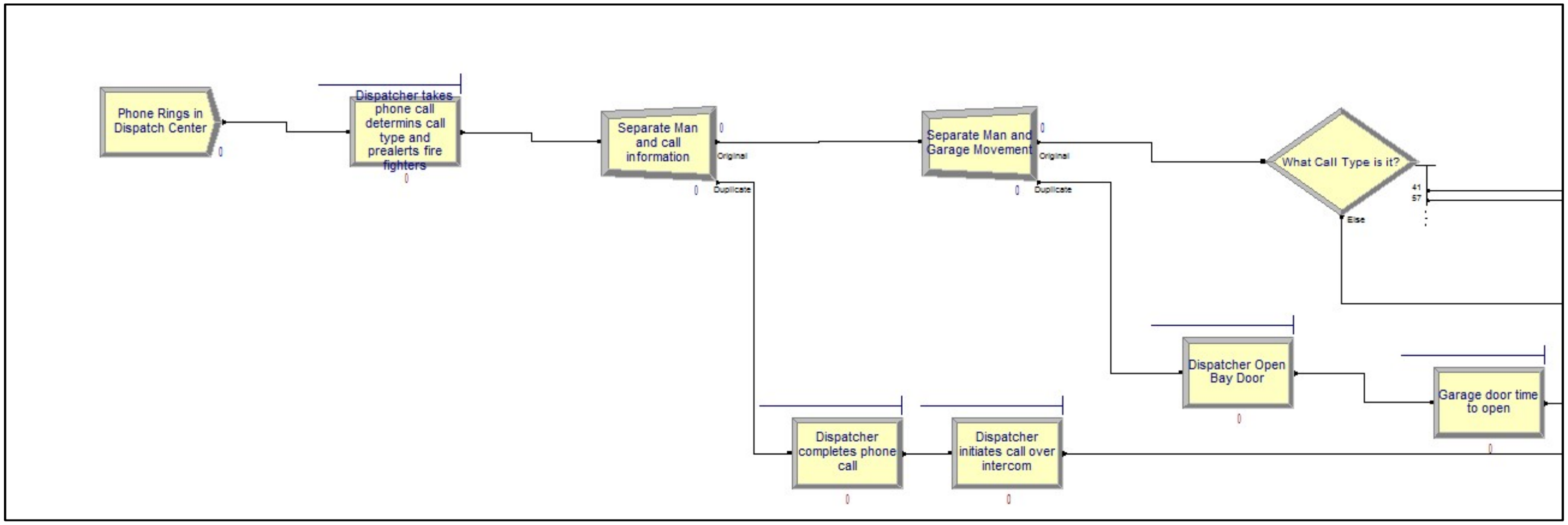


Figure 29: ARENA Alternative Model #2 Change

The third change my model will implement is changing the layout of the station allowing the rooms with the highest occupancy rate to be closer to the bay than rooms with a lower occupancy rate. This will allow for the travel time between rooms and the bay to be a low as possible. Table 5 shows the change in times for the new configuration.

Table 5: Alternative Model #3 Travel Time Changes

Room	Occupancy	Avg Current Travel Time (seconds)	Avg New Travel Time (seconds)
Dorms	22%	25.6	21.5
Kitchen	20%	32.7	25.6
Recreation Room	19%	37.3	29.5
Bay	14%	0	0
Training Room	10%	21.5	31.6
Gym	7%	31.6	32.7
Restroom/Shower	5%	29.5	34.1
Admin	3%	34.1	37.3

B.8 Output Analysis

When implementing all three of these changes the total turn-out-time average changed from an average turn-out-time of 2.31 minutes to an average turn-out-time of 1.64 minutes, which meets the NFPA guideline of 2 minutes.

When attempting to decrease overall turn-out-time at Fire Station #1, three potential changes were implemented. The first change gives the dispatch center the ability to open the garage door eliminating the need for a firefighter to do the job. This option also allows for the garage door to begin opening sooner in the process increasing the odds that the garage door does not slow down progress. The second change gives the dispatch center the ability to pre-warn first responders to an emergency. In doing so, firefighters are able to begin their sequence of events much sooner while the dispatcher continues to gather information from the caller. While this change could potentially lead to false alerts, the benefit of the pre-warning may overweigh the negatives. The third change implemented is a fire station reconfiguration. This reconfiguration is based on room occupancy levels and their distance from the fire trucks. The higher occupancy level the closer the room is. I analyzed several different combinations, of these changes to include all changes made, each change independently of another, and just the ability for the dispatcher to pre-warn and open the garage doors. The results of these combinations proved to be very insightful. When all changes were made, the turn-out-time dropped 28.9 percent from an average of 2.31 minutes to 1.64 minutes. Not far from that, the ability to both pre-warn and open the garage gave an average of 1.67 minutes, a difference of 27.5 percent. The following table shows the change for all combinations.

Model	Minimum (mins)	Average (mins)	Maximum (mins)	% change in Avg from baseline
Baseline (no change)	1.3474	2.3064	3.0554	0.00%
All Changes	1.0448	1.6409	2.2122	-28.85%
Garage Alone	1.3584	2.2372	3.1823	-3.00%
Pre-warn Alone	0.9344	1.7469	2.2751	-24.26%
Reconfiguration Alone	1.3474	2.2798	3.0347	-1.15%
Both Pre-Warn and Garage	1.0235	1.6713	2.1968	-27.54%

Figure 30: Alternative Model Comparison

Using confidence intervals with an alpha of 0.95 between the baseline and alternate models the following shows the statistical validity of the models:

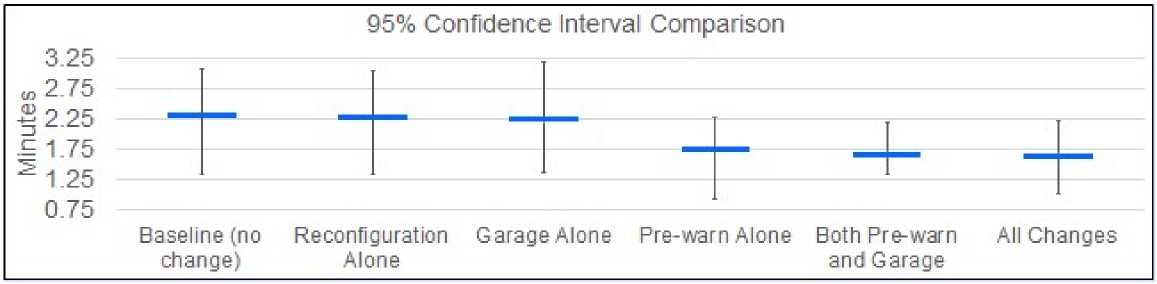


Figure 31: Confidence Interval Comparison

This shows that making the reconfiguration or garage change alone is not statistically different. Making the pre-warn alone, both the pre-warn and garage, and all changes are statistically different from the baseline model and are the only models that should be taken into consideration when deciding upon a solution.

Appendix C. Extended Abstract and Poster Presented at the 2016 Winter Simulation Conference

Abstract

Fire station turn-out-time is vitally important to firefighters' ability to provide lifesaving services. Turn-out-time consists of two phases: first, dispatch by a controller in a 911 call center; second, turn-out, in which controllers notify the responders, and responders prepare for the emergency by donning their personal protective equipment and boarding their emergency vehicle. The National Fire Protection Agency (NFPA) suggests a two-minute turn-out-time, yet fire stations do not always meet this goal due to several factors. This case study considered configuration, procedural, environmental, and behavioral factors at a single fire station using discrete-event simulation with the aim to decrease turn-out-time. Implementing a procedural and behavioral change allowing phase two to commence before phase one was completed decreasing the simulated turn-out-time by 24.3%. This change increases the ability for the case study fire station to provide lifesaving services and meet the NFPA goal.

C.1 Introduction

Every moment is critical for emergency responders as they attempt to prevent negative outcomes. Mattsson and Juas (1997) found that responses delayed by five minutes could allow overall damage to increase by 97-percent for tightly coupled events such as structural fires, road accidents, or drowning cases. Similarly, the arrival of responders in 5 minutes instead of 7 can double the probability of survival in heart attack victims (Pell et al., 2001). Emergency response professionals know the importance of a timely response and must be able to arrive on scene quickly, yet the systematic factors that contribute to the delay have received little attention in the literature (Weninger, 2004).

Fire stations are required to meet minimum response times to be accredited ("CPSE," 2016). The measured response time consists of: first, dispatch by a controller in a 911 call center; second, turn-out, in which controllers notify the responders, and responders prepare for the emergency by donning their personal protective equipment and boarding their emergency vehicle; and third, traveling to the emergency location. NFPA guidelines for the first two phases of response time is two minutes. A 2015 study of an Air Force fire station found their turn-out times were met only 47% of the time ("An Analysis of Fire and Emergency Services Aggregate Response Times," 2015). This fire station serves as the case study for this research.

Given the observed difficulties to exit the fire station within two minutes, this study sought to understand--through simulation--the procedural, environmental, behavioral, and configurable factors that affected the first two phases and to discover what changes can be implemented at the fire station to meet the two-minute guideline.

C.2 Methodology

A time-and-motion study was conducted at the sample fire station. Task times of the activities were fit to probability distributions and incorporated into a baseline simulation model created with Rockwell's ARENA software. The baseline model was then validated by comparing simulated response times to historical data. After validation, alternative models with specific system modifications were built incorporating procedural, environmental, behavioral, and configuration changes to the system. Each model was simulated 300 times showing the fire station's likelihood of meeting the two-minute guideline. The alternative model changes included:

1. Re-organizing dispatch procedures to include a pre-warn notification system
2. Re-configuring fire station layout
3. Remote access to fire station garage door opening system and responsibility realignment

C.3 Results/Discussion

Baseline model validation was conducted using a Student's t-test. The baseline simulation data was compared to five years of data collected by the fire station for the actual time it took the fire station to complete the first two phases. The results of the test, $t(299)=2.33$, $p=0.59$, indicated that the baseline model and reality are statistically equal.

Running the simulations in ARENA identified the critical nodes within the system. These critical nodes were used to create alternative models. The alternative models successfully identified improvement areas that enable responders to meet the response times successfully. Re-organizing dispatch procedures to include a pre-warn notification system yielded a 24.3% decrease, providing remote access to the garage door opening system provided a 3.0% decrease, and reconfiguring the fire station layout generated a 1.2% decrease in response time.

This study showed the value of incorporating procedural, environmental, behavioral, and configurable factors when determining fire station design and operational measures to provide the emergency responders to supply the life, limb, and property saving services expected of them.

C.4 Future Work

This research used discrete-event simulation to determine a fire station's ability to meet specific guidelines. This concept can help inform engineering design efforts of new emergency services facilities by allowing decision makers to assess the effectiveness of a design to meet a pre-determined level of service. This would allow for designs that contribute to the overall effectiveness of the system. Future studies should apply this method to other facility design efforts and operational procedures.

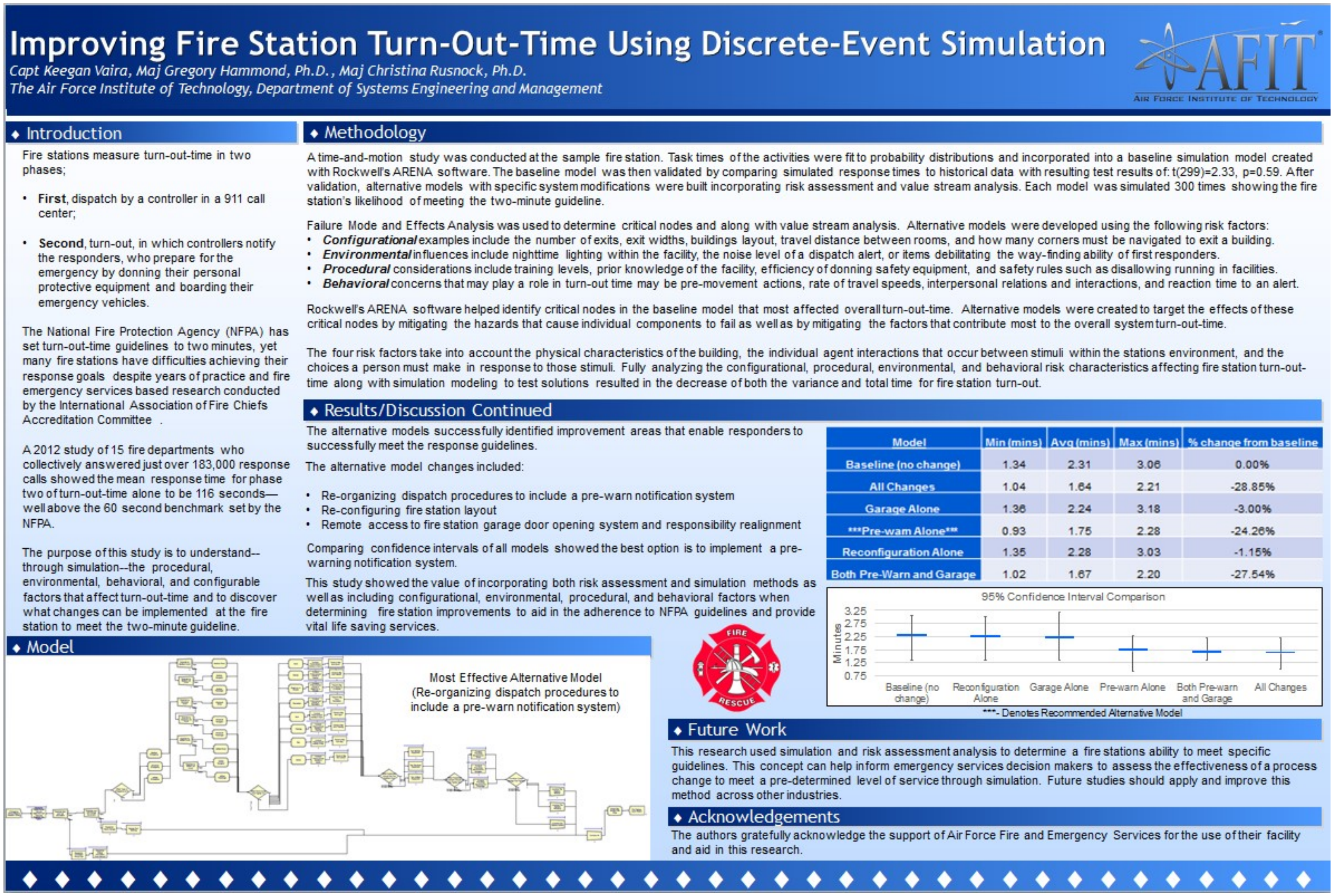


Figure 32: Winter Simulation Conference Poster

Appendix D. IRB Exemption

DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OHIO

7 December 2015

MEMORANDUM FOR MAJ GREGORY HAMMOND

FROM: Jeffrey A. Ogden, Ph.D.
AFIT IRB Research Reviewer
2950 Hobson Way
Wright-Patterson AFB, OH 45433-7765

SUBJECT: Approval for exemption request from human experimentation requirements (32 CFR 219, DoDD 3216.2 and AFI 40-402) for An Analysis of Air Force Design Guide (UFC 4-730-10) Effectiveness

1. Your request was based on the Code of Federal Regulations, title 32, part 219, section 101, paragraph (b) (2) Research activities that involve the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior unless: (i) Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) Any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

2. Your study qualifies for this exemption because you are not collecting and reporting sensitive data, which could reasonably damage the subjects' financial standing, employability, or reputation. Further, you are not collecting and reporting any demographic data which could realistically be expected to map a given response to a specific subject.

3. This determination pertains only to the Federal, Department of Defense, and Air Force regulations that govern the use of human subjects in research. Further, if a subject's future response reasonably places them at risk of criminal or civil liability or is damaging to their financial standing, employability, or reputation, you are required to file an adverse event report with this office immediately.

X

Jeffrey A. Ogden, Ph.D.
IRB Exempt Determination Official

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (AETC)

2 December 2015

MEMORANDUM FOR AFIT EXEMPT DETERMINATION OFFICIAL

FROM: AFIT/ENV
2950 Hobson Way
Wright Patterson AFB OH 45433-7765

SUBJECT: Request for exemption from human experimentation requirements (32 CFR 219, DoDD 3216.2 and AFI 40-402) for An Analysis of Air Force Design Guide (UFC 4-730-10) Effectiveness

1. The purpose of this is to collect key motion-time indicators to correlate fire department design to response times. The research will observe the full process within the fire department itself pertaining to responses from dispatch to the fire engine leaving the station. This research will potentially show correlations between room occupancy and call frequency allowing for a new building layout to minimize travel time, illuminate pre-movement activities necessary to accomplish before response and suggest improved methods to speed up the process, and pick out and minimize overall inefficiencies slowing the response time required of the department. The end goal is to improve the Fire Department Design Guide (UFC-4-730-10). No PII will be collected throughout the observations.

2. This request is based on the Code of Federal Regulations, title 32, part 219, section 101, paragraph (b) (2) Research activities that involve the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior unless: (i) Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) Any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation and (5) Research and demonstration projects that are conducted by or subject to the approval of federal department or agency heads, and are designed to study, evaluate, or otherwise examine public benefit or service programs, procedures for obtaining benefits or services under those programs, possible changes in or alternatives to those programs or procedures, or possible changes in methods or levels of payment for benefits or services under those programs.

3. The following information is provided to show cause for such an exemption:

a. Equipment and facilities: Study will be collected on paper forms to be printed with AFIT supplied paper and ink or through the computer using Microsoft Excel. Additional equipment includes a distance measuring device and a time measuring device. The Fire Department at Wright Patterson AFB will be the location for study completion.

b. Subjects:

Source of subjects: Subjects will be military and civilian personnel assigned to the Fire Department at Wright Patterson AFB.

Total number of subjects: No more than 100 subjects will be studied.

Inclusion/exclusion criteria: All personnel assigned to the Fire Department at Wright Patterson AFB that have agreed to participate in the study will be observed.

Age range: Subjects will be 18 years and older.

c. Timeframe: The survey will be administered during the 2016 calendar year.

d. Data collected: The study will be anonymous and will not collect any Personally Identifiable Information (PII). The information to be collected can be seen in attachment 1. The principal investigator will securely store paper copies and digital analysis files of completed studies.

e. Risks to Subjects: Risks to subjects that participate in this survey are minimal. Responses to survey questions will not be associated with individuals and will be kept confidential. Only the principal investigator and student researcher will have access to complete surveys.

f. Informed consent: All subjects assigned to the Fire Department at Wright Patterson AFB are selected to volunteer to participate in the survey. No adverse action is taken against those who choose not to participate. Subjects are made aware of the nature and purpose of the research. See attachment 4 for exact statements provided to subjects. Signed informed consent documents will be collected. Subjects will be given the opportunity to ask questions prior to participating in the study.

4. If you have any questions about this request, please contact Major Gregory Hammond (principal investigator) – Phone DSN 785-3636, ext. 7101; E-mail – gregory.hammond@afit.edu.

GREGORY D. HAMMOND, Maj, USAF
Principal Investigator

Attachments:
1. Data Collection Template (Excel)
2. CITI Training Certificates
3. Curriculum Vitae
4. Statement for Participants

Attachment 4: Written Statement for Participants

I ask you to participate in a time-motion study. This study is part of research examining the effectiveness of the current AF Fire Department Design Guide in regards to its layout, flow, and integration of functions. I will use the results to potentially enhance response times across the force and reduce the risk of damage and loss of life in critical responses. This study will last up to one year in which I will observe and record data indicative of a time-motion study. Such data includes, but is not limited to, room occupation levels, pre-movement actions, and distance-time calculations. No work will be required outside of normal duty hours and no interruptions to any assigned duties will occur.

Your participation in this study is voluntary and anonymous. No names or positions are associated with any observations made, there is no penalty for non-participation, and no anticipated risks are associated with participation.

I will collect no personally identifiable information (PII). By participating in this study, you certify that you have read and understand all of the information provided above.

Appendix E: Data

Table 6: Baseline Fire Station Turnout Time Actual

Baseline Fire Station Turnout Time Actual (Minutes)									
Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry
0-30	31-60	61-90	91-120	121-150	151-180	181-210	211-240	241-270	271-300
1.62	1.00	0.82	1.57	1.15	1.27	0.92			
1.98	1.92	1.95	1.02	1.15	1.15	0.82			
1.65	0.85	1.90	1.73	1.83	1.68	1.90			
1.73	1.65	1.13	1.65	1.67	1.70	0.97			
1.92	1.75	1.43	1.62	0.87	1.03	1.78			
0.85	1.57	0.80	1.25	1.00	1.25	0.82			
0.92	1.13	1.00	1.82	1.67	1.90	1.78			
1.30	2.00	1.95	1.57	1.30	0.77	1.68			
1.87	1.15	1.75	1.10	1.03	1.63	1.98			
1.48	1.78	1.43	1.50	1.67	1.50	1.38			
0.95	0.90	1.82	1.08	0.83	1.30	0.92			
1.72	1.53	1.35	1.47	1.37	1.08	1.17			
1.27	0.77	1.38	1.07	1.68	1.70	1.12			
1.78	1.85	1.53	1.17	1.43	1.50	0.77			
1.78	1.78	1.37	1.95	1.02	1.75	1.03			
1.57	1.95	1.00	1.67	1.92	1.98	1.18			
1.47	0.97	1.05	1.07	1.80	0.78	1.33			
0.83	1.37	1.05	1.55	0.95	1.00	1.03			
1.55	1.43	1.00	1.22	0.77	1.02	1.83			
1.15	0.98	1.80	0.83	0.77	1.15	0.75			
1.78	1.22	1.50	1.17	0.78	1.23	1.55			
1.18	0.87	1.25	1.78	1.00	0.87	0.87			
0.93	1.43	0.93	0.90	0.78	1.50	1.83			
1.27	1.65	1.78	1.27	1.95	1.18				
1.85	1.77	1.20	1.37	1.40	1.45				
1.98	0.93	1.10	1.98	1.70	1.88				
1.45	1.70	0.98	1.98	0.83	1.63				
1.22	1.25	1.83	1.42	1.42	1.58				
2.00	0.95	1.78	1.87	0.87	1.10				
1.75	1.58	1.58	1.83	0.87	1.68				

Table 7: Baseline Fire Station Turnout Time Simulated

Baseline Fire Station Turnout Time Simulated (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
1.24	1.27	1.44	1.60	1.83	1.67	0.90	1.82	1.73	1.59
1.84	1.28	1.27	1.56	1.39	1.69	1.28	1.73	1.24	1.78
1.31	1.24	2.02	1.40	1.45	1.31	1.36	1.29	1.17	1.21
1.46	1.14	1.40	1.23	1.20	1.25	1.97	1.32	1.81	1.59
1.26	1.84	1.22	1.70	1.31	1.72	1.18	1.75	1.32	1.86
1.36	1.44	0.70	1.22	1.55	1.09	1.86	1.41	1.71	1.44
1.27	1.60	1.38	0.89	1.32	1.00	1.10	1.32	1.47	1.57
1.43	1.24	1.69	1.67	1.59	1.26	1.35	1.06	1.74	1.50
1.35	1.43	1.86	1.46	1.79	1.08	1.72	1.39	1.46	1.35
1.47	1.33	1.35	1.49	1.52	1.87	1.28	1.70	1.13	1.61
0.75	0.89	1.61	1.49	1.76	1.72	1.37	0.72	1.46	1.32
1.41	1.47	1.65	1.16	1.89	1.67	1.64	1.29	1.11	1.26
1.39	1.51	1.35	1.25	1.19	1.86	1.17	1.34	1.49	1.43
1.00	1.11	1.30	1.38	1.38	1.32	1.31	1.26	1.31	1.38
1.36	1.74	1.30	1.74	1.86	1.53	1.69	1.87	1.42	1.63
1.19	1.23	1.84	1.00	1.03	1.41	1.54	1.42	1.17	1.43
1.19	1.74	1.77	1.29	0.98	1.39	1.17	1.26	1.00	1.18
0.84	1.49	1.48	1.42	1.31	1.42	1.00	1.19	1.87	1.23
1.71	1.40	1.37	1.70	1.42	1.50	1.52	1.51	2.08	1.25
1.09	1.64	1.94	1.61	0.79	1.49	1.30	1.49	1.78	1.76
1.42	1.33	1.29	1.84	1.34	0.74	1.93	1.40	1.23	1.32
0.96	1.20	1.29	1.65	1.34	1.00	1.52	1.73	1.75	1.32
1.11	1.27	1.15	1.22	1.53	1.68	1.71	1.07	0.84	1.32
0.99	1.17	1.71	1.74	1.06	1.76	1.13	1.51	0.85	1.07
1.71	1.07	1.51	1.27	1.43	1.29	1.63	1.07	1.73	1.08
1.34	1.30	0.98	1.80	1.00	1.35	0.75	1.45	1.27	1.70
0.67	1.13	1.44	1.57	1.13	1.01	1.74	1.75	1.23	1.39
1.25	1.34	1.74	1.30	0.68	1.26	1.54	1.15	1.51	1.29
1.17	0.91	1.98	1.39	1.65	0.75	1.42	1.34	1.28	1.30
1.20	1.29	1.29	1.56	1.30	1.31	1.85	1.73	1.18	1.65

Table 8: Fire Station #1 Turnout Time Actual

Fire Station #1 Turnout Time Actual (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
0.82	1.03	1.00	1.63						
1.17	0.78	1.72	0.87						
1.08	1.82	1.47	1.95						
1.20	1.13	1.25	1.83						
1.30	0.98	0.77	1.05						
1.05	1.12	1.45	0.95						
1.20	1.30	1.70	1.62						
1.28	1.28	0.83	0.98						
1.88	1.42	1.28	1.88						
1.30	0.88	2.00	0.93						
1.08	0.82	1.62	1.62						
1.88	1.20	1.28							
0.97	1.20	1.22							
1.28	0.82	1.08							
1.72	1.28	0.95							
1.20	0.83	1.25							
0.83	0.75	1.05							
1.48	1.05	1.53							
1.08	1.02	1.00							
1.22	1.00	1.12							
1.72	1.10	1.00							
1.47	0.93	0.93							
1.97	1.47	1.07							
1.48	1.85	1.10							
1.73	1.38	1.38							
1.47	1.35	1.30							
0.75	0.83	1.08							
1.42	0.83	1.22							
1.00	0.88	0.97							
0.95	1.12	0.80							

Table 9: Fire Station #1 Turnout Time Simulated

Fire Station #1 Turnout Time Simulated (Minutes)									
Entry 0-30	**Entry 31-60**	**Entry 61-90**	**Entry 91-120**	**Entry 121-150**	**Entry 151-180**	**Entry 181-210**	**Entry 211-240**	**Entry 241-270**	**Entry 271-300**
1.04	0.89	1.46	1.50	1.04	1.42	1.62	1.88	1.62	1.34
1.11	0.91	1.24	1.51	1.33	1.13	1.21	1.54	1.15	1.63
1.25	1.04	1.37	1.10	1.63	1.06	1.11	1.09	1.43	1.28
1.33	0.96	1.45	1.46	1.49	1.20	1.11	1.07	1.58	1.37
1.10	1.55	1.31	1.72	1.17	1.10	1.03	1.51	1.13	1.50
1.07	1.67	1.25	1.55	1.18	1.01	1.27	1.17	1.30	1.19
1.11	1.82	0.80	1.01	0.99	1.15	1.61	1.03	1.14	1.30
1.20	1.35	1.40	1.02	1.17	1.60	1.06	1.47	1.70	1.09
1.12	1.55	1.14	1.49	1.30	1.64	1.56	1.12	1.22	1.11
1.52	1.10	1.78	1.70	0.98	0.90	1.03	1.41	0.92	1.45
1.60	1.41	1.11	1.13	1.22	1.36	1.00	0.72	1.23	1.05
1.11	1.14	1.34	1.07	1.04	1.57	1.31	1.02	0.90	1.57
1.58	1.18	1.06	1.21	1.51	1.10	1.59	1.07	1.14	1.05
0.90	1.65	1.48	1.33	0.99	1.66	1.40	0.96	1.03	1.13
1.31	1.07	1.35	0.68	1.62	0.99	0.92	1.58	1.21	1.50
1.37	0.98	1.50	1.16	0.87	1.16	1.17	1.23	1.56	1.24
1.49	1.09	1.50	0.98	1.05	1.48	1.46	0.99	1.62	0.91
1.09	1.60	1.29	1.07	1.42	1.05	1.09	0.90	1.56	0.98
1.14	1.38	1.21	1.25	0.79	1.79	1.54	1.23	1.76	0.99
0.99	1.59	1.35	0.94	1.12	1.26	1.64	1.20	1.47	1.63
1.22	1.53	0.97	1.18	0.95	1.70	1.56	1.20	1.09	1.16
1.32	1.73	1.12	1.48	0.93	1.69	0.99	1.30	1.55	1.04
1.72	1.51	0.74	1.01	1.56	1.62	1.12	1.10	0.84	1.06
1.06	1.57	1.11	0.85	1.41	1.49	0.98	1.21	0.85	1.65
0.96	1.81	1.12	1.28	1.23	1.19	1.47	1.56	1.56	1.02
1.46	1.12	1.53	1.47	1.07	1.23	1.06	1.23	0.98	1.41
1.05	0.91	0.97	1.05	1.09	1.26	1.55	1.54	1.10	1.06
0.76	0.98	1.43	1.17	1.02	1.29	1.51	0.99	1.45	1.13
1.15	1.46	1.07	0.97	1.31	1.53	1.54	1.11	0.99	1.06
1.04	1.29	0.84	1.58	1.65	1.56	1.63	1.63	1.00	1.39

Table 10: Fire Station #2 Turnout Time Actual

Fire Station #2 Turnout Time Actual (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
1.62	1.53								
1.88									
1.97									
0.75									
1.12									
1.22									
0.88									
0.88									
1.17									
0.82									
1.17									
1.57									
0.80									
1.00									
0.83									
1.32									
0.77									
1.23									
1.80									
1.03									
1.00									
0.83									
1.08									
1.02									
1.92									
1.07									
1.90									
0.97									
1.42									
1.52									

Table 11: Fire Station #2 Turnout Time Simulated

Fire Station #2 Turnout Time Simulated (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
1.04	0.84	1.43	1.66	1.20	1.53	1.60	1.91	1.54	1.28
1.05	0.85	1.41	1.67	1.34	0.98	1.35	1.49	1.09	1.45
1.25	1.28	1.20	1.22	1.85	1.01	1.04	0.96	1.29	1.11
1.45	0.85	1.52	1.38	1.95	1.14	1.25	1.01	1.49	1.35
1.00	1.59	1.26	1.71	1.01	1.24	0.98	1.63	1.15	1.68
1.17	1.54	1.29	1.65	1.38	1.03	1.11	1.17	1.34	1.34
1.28	1.66	0.84	1.17	1.15	1.16	1.64	1.15	0.87	1.36
1.40	1.54	1.48	1.11	1.42	1.52	1.04	1.57	1.54	0.95
1.06	1.59	1.09	1.38	1.39	1.62	1.61	1.09	1.07	1.06
1.38	0.95	1.61	1.60	1.06	0.76	0.86	1.39	0.79	1.63
1.48	1.24	0.90	0.98	1.22	1.56	1.09	0.72	1.17	0.99
1.31	1.11	1.19	1.17	1.02	1.52	1.13	0.95	0.96	1.31
1.42	1.21	1.24	1.38	1.36	1.26	1.51	1.01	1.13	0.98
0.93	1.80	1.66	1.07	1.14	1.40	1.24	1.15	1.23	1.17
1.57	0.92	1.21	0.68	1.86	0.87	1.13	1.77	1.09	1.62
1.48	1.00	1.49	1.41	0.99	1.32	1.09	1.38	1.73	1.19
1.49	1.18	1.60	0.86	1.05	1.66	1.22	1.15	1.48	0.95
0.95	1.49	1.39	1.21	1.37	0.91	1.21	0.87	1.56	1.13
1.07	1.31	1.05	1.10	0.75	2.04	1.80	1.17	1.51	1.04
1.13	1.44	1.43	1.17	1.27	1.43	1.71	1.31	1.50	1.76
1.41	1.49	0.81	1.05	1.02	1.85	1.71	1.35	1.14	1.00
1.47	1.62	1.15	1.57	0.80	1.74	0.93	1.11	1.39	1.15
1.87	1.85	0.74	1.08	1.80	1.52	1.05	0.96	0.84	1.27
1.14	1.43	0.98	1.05	1.53	1.58	0.95	1.33	0.85	1.66
0.87	1.65	1.07	1.41	1.05	1.35	1.45	1.77	1.55	0.97
1.63	1.12	1.64	1.64	1.23	1.67	0.87	1.47	0.91	1.59
1.18	0.75	0.91	1.13	1.12	1.38	1.50	1.75	1.13	1.07
0.82	0.85	1.55	1.44	0.76	1.34	1.55	0.92	1.43	1.14
1.10	1.48	1.31	0.84	1.36	1.47	1.31	1.10	1.13	1.10
0.99	1.17	0.71	1.74	1.97	1.60	1.64	1.48	1.03	1.40

Table 12: Fire Station #3 Turnout Time Actual

Fire Station #3 Turnout Time Actual (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
1.70									
0.75									
0.83									
1.42									
1.12									
1.33									
0.75									
0.85									

Table 13: Fire Station #3 Turnout Time Simulated

Fire Station #3 Turnout Time Simulated (Minutes)									
Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry
0-30	**31-60**	**61-90**	**91-120**	**121-150**	**151-180**	**181-210**	**211-240**	**241-270**	**271-300**
1.02	0.84	1.28	1.56	1.45	1.29	1.52	1.80	1.50	1.06
1.43	0.86	1.57	1.40	1.16	0.89	1.14	1.50	0.93	1.33
1.53	1.79	1.17	1.12	1.76	1.29	1.05	1.05	1.30	1.50
1.37	1.30	1.45	1.29	1.48	1.15	1.16	1.54	1.47	0.92
1.05	1.47	1.26	1.59	1.62	1.14	1.24	1.53	1.25	1.29
1.47	1.47	1.20	1.50	1.29	0.88	1.03	1.06	1.36	1.48
1.13	1.57	0.75	1.32	1.35	1.45	1.62	1.34	0.89	1.02
1.23	1.32	1.39	1.62	1.33	1.53	1.02	1.50	1.45	1.11
1.07	1.30	1.09	1.28	1.28	1.74	1.51	0.98	1.16	1.57
1.38	1.16	1.53	1.62	0.97	1.58	0.88	1.32	0.80	1.26
1.49	1.24	1.28	1.00	1.00	1.47	0.89	0.72	1.18	1.26
1.20	1.31	1.16	1.07	0.93	1.52	1.22	0.96	0.96	0.98
1.44	1.07	1.11	1.31	1.28	1.52	1.52	1.02	1.04	0.97
1.83	1.40	1.56	0.99	1.06	1.40	1.26	1.05	1.09	1.35
1.56	0.94	1.22	1.47	1.68	0.84	0.99	1.67	1.06	1.00
1.42	1.55	1.49	1.91	0.90	1.23	1.09	1.39	1.64	1.42
1.40	1.09	1.47	0.84	0.87	1.43	1.26	1.06	1.35	1.34
0.87	1.42	1.30	1.45	1.32	1.27	0.95	0.78	1.40	0.88
0.99	1.32	1.07	1.01	1.45	1.93	1.44	1.17	1.44	1.56
1.04	1.54	1.37	1.55	0.91	1.16	1.52	1.23	1.52	1.19
1.32	1.48	1.44	0.98	0.97	1.78	1.60	1.15	1.05	0.78
1.38	1.54	1.02	1.56	0.81	1.79	1.68	1.14	1.41	1.34
1.55	1.65	1.62	0.99	1.69	1.56	1.42	0.90	0.84	0.90
1.63	1.41	1.43	1.54	1.33	1.50	1.55	1.30	1.52	1.51
1.23	1.56	1.08	1.32	0.96	1.27	1.38	1.65	1.05	0.91
1.44	1.03	1.61	1.36	1.36	1.17	0.90	1.09	1.41	1.07
0.96	0.77	0.92	1.00	0.96	1.20	1.50	1.57	0.84	1.54
1.37	0.78	1.47	1.65	0.78	1.30	1.38	0.86	1.52	1.61
0.99	1.39	1.21	0.85	1.25	1.47	1.23	1.06	1.45	0.97
0.99	1.14	0.73	1.65	1.87	1.50	1.57	1.49	0.92	1.45

Table 14: Fire Station #4 Turnout Time Actual

Fire Station #4 Turnout Time Actual (Minutes)									
Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry
0-30	**31-60**	**61-90**	**91-120**	**121-150**	**151-180**	**181-210**	**211-240**	**241-270**	**271-300**
0.98	1.22	1.33	1.42	0.83	1.53				
1.33	1.15	0.92	1.03	1.53	0.82				
0.82	0.83	0.95	0.83	1.02	1.65				
1.98	1.45	1.53	1.92	0.97	1.33				
0.87	0.87	1.17	0.87	1.48	1.38				
0.83	0.88	1.15	1.83	1.25	1.20				
1.03	0.83	0.87	1.33	1.10	1.53				
1.10	0.77	1.12	1.53	1.90	1.87				
1.85	1.25	0.87	1.05	1.90	0.80				
0.97	0.93	0.88	0.78	1.67	1.33				
1.77	1.60	0.83	1.08	0.83	1.82				
1.23	1.90	1.03	1.57	1.32	1.50				
0.75	0.82	0.75	1.50	1.33	0.78				
1.08	1.58	0.88	0.92	1.65	1.35				
1.92	1.72	0.78	1.53	0.95	1.57				
0.88	1.32	1.63	0.88	0.82					
0.97	0.92	1.18	0.93	0.87					
0.82	1.65	1.10	0.80	1.60					
1.13	1.78	1.43	1.17	0.82					
1.37	1.25	1.43	1.10	1.18					
1.08	1.65	1.48	1.78	1.47					
0.85	1.02	1.55	0.80	1.25					
1.10	1.28	0.83	0.98	1.45					
1.82	1.40	1.72	1.45	1.60					
1.30	1.00	0.82	1.32	1.00					
0.93	0.77	0.90	1.37	1.67					
0.83	1.03	0.95	0.78	1.15					
0.95	1.75	1.73	0.82	1.42					
1.18	0.88	0.85	1.33	1.05					
0.88	1.33	0.90	1.08	0.93					

Table 15: Fire Station #4 Turnout Time Simulated

Fire Station #4 Turnout Time Simulated (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
0.94	0.81	1.19	1.43	1.03	1.26	1.48	1.57	1.45	1.25
1.07	0.83	1.15	1.42	1.13	0.89	1.13	1.46	0.93	1.49
1.16	0.99	1.23	1.14	1.66	0.98	1.01	0.93	1.26	1.02
1.29	0.88	1.46	1.29	1.48	1.11	1.05	0.98	1.45	1.11
1.01	1.43	1.23	1.51	0.99	1.07	0.91	1.50	0.90	1.48
1.00	1.47	1.06	1.54	1.17	0.84	0.99	1.08	1.31	1.18
1.09	1.57	0.75	0.97	0.90	1.03	1.52	0.95	0.89	1.28
1.15	1.32	1.36	0.81	1.24	1.49	0.98	1.36	1.45	0.98
1.04	1.32	1.06	1.19	1.21	1.63	1.43	0.86	1.13	0.92
1.44	0.97	1.52	1.63	0.91	0.72	0.88	1.26	0.80	1.25
1.45	1.19	0.92	1.01	1.02	1.39	1.09	0.72	1.14	0.96
1.10	0.97	1.11	0.99	0.94	1.49	1.22	0.92	0.93	1.42
1.44	1.09	1.02	1.12	1.28	1.08	1.48	0.98	0.95	0.95
0.83	1.54	1.48	0.98	0.99	1.37	1.26	0.96	1.00	0.85
1.30	0.94	1.23	0.68	1.61	0.85	0.91	1.58	1.02	1.46
1.39	0.85	1.49	1.10	0.86	1.15	1.09	1.16	1.55	1.19
1.39	1.02	1.41	0.85	0.87	1.42	1.26	0.98	1.26	0.69
0.86	1.43	1.27	1.04	1.29	0.93	0.96	0.78	1.39	0.97
0.94	1.28	1.07	1.01	0.75	1.79	1.45	1.13	1.44	0.85
0.96	1.47	1.26	0.93	0.91	1.19	1.51	1.24	1.39	1.55
1.21	1.44	0.83	0.97	0.89	1.44	1.49	1.12	0.97	0.93
1.31	1.47	0.98	1.47	0.82	1.68	0.93	1.14	1.41	0.98
1.57	1.62	0.74	0.90	1.51	1.58	0.95	0.90	0.84	0.97
0.88	1.35	0.99	0.84	1.34	1.41	0.82	1.20	0.85	1.49
0.84	1.55	1.04	1.36	0.96	1.19	1.31	1.54	1.36	0.94
1.44	0.96	1.53	1.46	1.08	1.18	0.90	1.10	0.88	1.37
1.00	0.77	0.89	0.96	0.92	1.16	1.47	1.45	0.94	1.01
0.76	0.77	1.39	1.19	0.79	1.24	1.42	0.83	1.33	1.05
0.96	1.45	1.06	0.86	1.21	1.43	1.24	1.02	0.98	0.93
0.82	1.14	0.73	1.59	1.64	1.46	1.49	1.44	0.87	1.37

Table 16: Fire Station #5 Turnout Time Actual

Fire Station #5 Turnout Time Actual (Minutes)									
Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry
0-30	**31-60**	**61-90**	**91-120**	**121-150**	**151-180**	**181-210**	**211-240**	**241-270**	**271-300**
0.83									
0.85									
1.13									
0.90									
1.65									
0.92									
1.50									
1.42									
0.92									
1.00									
0.98									
1.42									
1.38									
1.05									
1.52									
1.00									
1.33									
0.92									
1.25									
1.85									
1.83									

Table 17: Fire Station #5 Turnout Time Simulated

Fire Station #5 Turnout Time Simulated (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
0.95	0.85	1.41	1.56	1.09	1.32	1.58	1.77	1.48	1.23
1.05	0.81	1.18	1.45	1.22	1.04	1.16	1.45	0.98	1.44
1.20	1.07	1.21	1.10	1.73	0.96	1.09	0.92	1.24	1.01
1.35	0.86	1.46	1.31	1.49	1.09	1.14	0.96	1.47	1.33
0.99	1.57	1.21	1.58	0.98	1.13	0.92	1.51	1.14	1.54
1.07	1.48	1.17	1.47	1.27	1.01	1.01	1.04	1.38	1.24
1.16	1.59	0.74	1.06	0.94	1.06	1.60	0.96	0.87	1.24
1.27	1.33	1.37	1.09	1.31	1.48	0.99	1.48	1.47	0.97
1.02	1.57	1.04	1.26	1.25	1.72	1.53	1.07	1.10	1.13
1.43	0.96	1.54	1.70	0.95	0.70	0.86	1.33	0.79	1.33
1.43	1.19	0.91	0.99	1.05	1.46	1.07	0.72	1.12	0.94
1.18	1.07	1.11	1.05	1.02	1.47	1.13	0.90	0.92	1.40
1.43	1.12	1.09	1.16	1.33	1.15	1.46	0.96	1.02	0.93
0.92	1.57	1.54	1.00	1.05	1.35	1.24	1.03	1.07	1.16
1.46	0.93	1.21	0.68	1.66	0.87	0.97	1.65	1.03	1.53
1.38	0.98	1.49	1.28	0.89	1.21	1.09	1.18	1.62	1.19
1.38	1.07	1.42	0.83	1.00	1.41	1.17	1.05	1.47	0.93
0.88	1.48	1.34	1.11	1.27	0.92	1.20	0.85	1.35	1.03
1.08	1.26	1.05	1.03	0.75	1.85	1.48	1.11	1.43	1.02
1.03	1.52	1.34	1.07	0.94	1.22	1.54	1.25	1.51	1.56
1.27	1.39	0.81	0.99	0.90	1.76	1.58	1.20	1.03	0.93
1.37	1.53	1.13	1.54	0.80	1.70	0.91	1.12	1.40	1.05
1.61	1.71	0.74	0.97	1.66	1.62	0.97	0.92	0.84	1.01
1.13	1.37	0.98	0.91	1.33	1.47	0.94	1.21	0.85	1.72
0.82	1.57	1.02	1.30	0.98	1.25	1.34	1.62	1.43	0.93
1.52	1.02	1.59	1.53	1.14	1.16	0.88	1.18	0.86	1.43
1.03	0.75	0.87	1.11	1.10	1.13	1.46	1.52	0.95	1.14
0.82	0.79	1.45	1.23	0.77	1.28	1.53	0.87	1.35	1.00
1.06	1.52	1.19	0.84	1.23	1.39	1.24	1.05	1.05	1.08
0.82	1.16	0.72	1.67	1.85	1.48	1.53	1.42	1.01	1.35

Table 18: Fire Station #6 Turnout Time Actual

Fire Station #6 Turnout Time Actual (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
1.30									
1.08									
1.33									
0.75									
1.42									
1.30									
1.00									
1.33									
1.13									
1.17									
1.25									
1.15									
0.75									
1.15									
1.15									
1.17									
1.02									
1.08									
1.63									
1.25									

Table 19: Fire Station #6 Turnout Time Simulated

Fire Station #6 Turnout Time Simulated (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
0.91	0.82	1.23	1.53	1.09	1.25	1.41	1.77	1.47	1.15
1.01	0.77	1.03	1.33	1.10	0.86	1.15	1.42	0.89	1.42
1.16	1.04	1.16	1.10	1.73	0.93	0.96	0.89	1.20	0.98
1.34	0.81	1.39	1.26	1.45	1.06	1.10	0.92	1.36	1.23
0.89	1.38	1.18	1.57	0.88	1.12	0.88	1.50	0.96	1.54
1.06	1.46	1.17	1.45	1.27	0.83	0.95	1.04	1.29	1.24
1.09	1.50	0.70	1.10	0.80	1.02	1.59	0.87	0.83	1.24
1.21	1.28	1.37	0.80	1.30	1.44	0.96	1.48	1.41	0.93
0.98	1.27	1.01	1.24	1.24	1.71	1.43	0.91	1.07	0.91
1.39	0.91	1.49	1.54	0.95	0.67	0.82	1.32	0.84	1.32
1.40	1.18	0.86	0.95	0.94	1.45	0.84	0.72	1.08	0.90
1.18	0.92	1.06	1.04	0.89	1.44	1.13	0.86	0.88	1.35
1.39	0.98	1.12	1.02	1.25	1.12	1.43	0.92	1.01	0.89
0.83	1.36	1.54	0.95	1.04	1.31	1.20	1.02	1.06	0.85
1.45	0.89	1.18	0.68	1.66	0.83	0.97	1.65	0.99	1.52
1.36	0.80	1.49	1.27	0.88	1.21	1.09	1.07	1.61	1.19
1.37	1.07	1.32	0.79	0.85	1.40	1.13	1.04	1.33	0.72
0.83	1.35	1.21	1.10	1.24	0.88	0.93	0.72	1.34	1.03
0.93	1.24	1.01	0.98	0.75	1.85	1.32	1.07	1.39	0.83
1.02	1.52	1.31	1.06	0.88	1.08	1.56	1.21	1.36	1.45
1.27	1.38	0.77	0.95	0.90	1.40	1.54	1.05	1.02	0.87
1.36	1.52	0.97	1.53	0.76	1.62	0.87	1.07	1.35	1.04
1.52	1.69	0.74	0.97	1.56	1.48	0.92	0.87	0.84	0.91
0.94	1.32	0.94	0.90	1.26	1.45	0.81	1.20	0.85	1.58
0.78	1.52	0.99	1.29	0.92	1.24	1.34	1.62	1.42	0.89
1.49	1.03	1.44	1.43	1.13	1.12	0.83	1.02	0.82	1.42
0.91	0.71	0.84	0.91	0.90	1.07	1.43	1.54	1.03	0.94
0.82	0.75	1.46	1.11	0.73	1.27	1.31	0.77	1.26	0.98
0.90	1.51	1.19	0.80	1.22	1.38	1.25	1.01	1.04	0.91
0.82	1.10	0.69	1.64	1.84	1.47	1.55	1.37	1.00	1.31

Table 20: Fire Station #7 Turnout Time Actual

Fire Station #7 Turnout Time Actual (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
0.77	1.02	0.82	0.82						
0.92	1.62	1.15	1.73						
0.92	0.93	0.77	0.88						
1.22	0.93	1.12	0.77						
0.98	0.85	0.90	1.32						
0.88	1.15	0.98	1.42						
1.32	1.18	1.00	1.02						
1.05	0.85	1.20	0.87						
0.78	0.88	1.63	1.02						
0.90	1.83	0.83	0.88						
1.42	0.82	0.80	1.70						
0.93	1.30	1.12	1.10						
1.17	1.87	1.65	0.88						
1.00	1.45	1.13	1.00						
1.27	1.32	1.17	1.08						
0.98	1.77	1.08	1.17						
0.97	1.22	1.33	1.37						
1.82	0.75	0.90	1.68						
1.07	1.08	1.05							
0.90	1.33	0.85							
1.33	0.75	0.83							
0.88	1.28	0.93							
1.32	1.30	1.62							
1.22	0.88	1.10							
0.83	1.97	1.07							
1.32	1.08	0.78							
0.78	0.88	1.00							
1.37	1.58	0.95							
1.18	0.87	1.12							
1.13	1.33	1.33							

Table 21: Fire Station #7 Turnout Time Simulated

Fire Station #7 Turnout Time Simulated (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
0.96	0.81	1.28	1.58	1.13	1.30	1.48	1.82	1.52	1.18
0.99	0.76	1.10	1.39	1.22	0.83	1.19	1.41	0.88	1.50
1.14	1.17	1.19	1.14	1.77	0.92	0.94	0.88	1.21	0.92
1.38	0.89	1.43	1.23	1.43	1.04	1.17	0.91	1.42	1.09
0.93	1.37	1.16	1.61	0.96	1.16	0.86	1.55	1.02	1.57
1.10	1.42	1.24	1.47	1.31	0.89	0.93	1.08	1.26	1.28
1.14	1.51	0.76	1.06	0.88	1.10	1.64	0.93	0.90	1.29
1.25	1.33	1.40	0.88	1.34	1.43	0.95	1.52	1.39	0.99
0.97	1.30	0.99	1.28	1.30	1.76	1.52	0.99	1.05	0.98
1.38	0.98	1.33	1.61	0.99	0.73	0.89	1.36	0.81	1.37
1.49	1.30	0.93	1.01	1.00	1.49	0.90	0.72	1.07	0.89
1.22	0.94	1.03	1.09	0.94	1.35	1.22	0.84	0.87	1.43
1.45	1.06	1.16	1.09	1.31	1.16	1.42	0.95	1.06	0.88
0.83	1.41	1.58	0.93	1.08	1.53	1.27	1.07	1.12	0.89
1.49	0.95	1.23	0.68	1.48	0.86	1.01	1.69	0.96	1.61
1.43	0.86	1.51	1.32	0.92	1.25	1.09	1.13	1.67	1.19
1.41	1.11	1.38	0.85	0.84	1.44	1.18	1.08	1.37	0.79
0.81	1.41	1.35	1.14	1.29	0.86	0.97	0.79	1.39	1.06
1.02	1.24	1.04	0.96	0.75	1.95	1.37	1.01	1.45	0.91
1.06	1.56	1.36	1.10	0.87	1.15	1.51	1.24	1.51	1.50
1.33	1.37	0.84	0.88	0.94	1.80	1.58	1.13	1.06	0.87
1.40	1.56	1.03	1.57	0.82	1.74	0.85	1.15	1.49	1.08
1.51	1.67	0.74	1.01	1.71	1.55	0.96	0.85	0.84	0.95
1.00	1.30	0.92	0.95	1.32	1.52	0.88	1.25	0.85	1.63
0.77	1.50	0.98	1.34	0.90	1.28	1.38	1.67	1.47	0.88
1.56	1.05	1.60	1.34	1.17	1.18	0.91	1.08	0.81	1.40
0.95	0.78	0.93	1.00	0.97	1.06	1.41	1.59	1.08	0.92
0.82	0.86	1.50	1.25	0.80	1.31	1.39	0.76	1.19	0.94
1.01	1.41	1.23	0.86	1.27	1.36	1.31	1.00	1.08	0.99
0.82	1.05	0.74	1.67	1.89	1.56	1.58	1.36	0.94	1.30

Table 22: Fire Station #8 Turnout Time Actual

Fire Station #8 Turnout Time Actual (Minutes)									
Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry
0-30	**31-60**	**61-90**	**91-120**	**121-150**	**151-180**	**181-210**	**211-240**	**241-270**	**271-300**
1.53	1.38	1.07							
1.47	0.93	1.12							
1.33	1.02	1.95							
1.43	0.75	1.33							
1.00	0.92	0.83							
0.85	1.18	0.88							
1.23	1.68	1.17							
1.05	1.92	1.43							
1.07	1.08	1.05							
0.88	0.87	0.75							
0.87	0.93	1.92							
1.58	1.37	1.17							
1.68	0.88	1.88							
1.50	0.90	1.28							
1.22	1.35	1.28							
1.12	1.50	1.72							
1.38	0.87	1.22							
0.78	1.23	1.17							
1.25	1.48	1.80							
1.50	1.48	1.38							
1.75	1.80	1.38							
0.88	1.08	1.02							
1.13	1.18	0.95							
1.27	1.22	1.12							
1.08	1.23	1.22							
1.37	1.72	1.17							
1.63	1.33	1.20							
1.08	0.93	1.03							
1.35	0.83	1.77							
1.37	1.27	0.92							

Table 23: Fire Station #8 Turnout Time Simulated

Fire Station #8 Turnout Time Simulated (Minutes)									
Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry
0-30	**31-60**	**61-90**	**91-120**	**121-150**	**151-180**	**181-210**	**211-240**	**241-270**	**271-300**
1.10	0.81	1.33	1.52	1.21	1.38	1.48	1.93	1.55	1.18
0.97	0.76	1.12	1.40	1.16	0.90	1.25	1.41	0.94	1.48
1.20	1.29	1.22	1.22	1.76	0.92	0.94	0.88	1.21	1.03
1.46	0.87	1.41	1.31	1.42	1.04	1.38	0.91	1.42	1.13
1.01	1.37	1.16	1.69	0.94	1.25	0.92	1.64	1.05	1.65
1.22	1.48	1.30	1.55	1.39	0.92	1.03	1.13	1.35	1.35
1.17	1.59	0.85	1.20	0.88	1.29	1.74	0.93	0.89	1.36
1.24	1.55	1.49	0.92	1.42	1.44	0.99	1.58	1.46	0.98
0.97	1.42	0.99	1.38	1.40	1.63	1.62	1.03	1.01	1.02
1.38	0.97	1.52	1.64	1.07	0.71	0.88	1.45	0.80	1.64
1.49	1.15	0.92	1.00	1.00	1.57	0.93	0.72	1.07	0.89
1.32	1.02	1.13	1.25	0.87	1.43	1.22	0.84	0.87	1.42
1.44	1.07	1.25	1.10	1.30	1.22	1.42	0.94	1.14	0.88
0.83	1.49	1.66	1.00	1.15	1.52	1.26	1.16	1.24	0.92
1.58	0.94	1.22	0.68	1.85	0.84	1.14	1.78	1.03	1.50
1.49	0.85	1.51	1.42	0.99	1.33	1.09	1.13	1.75	1.19
1.50	1.19	1.37	0.84	0.88	1.52	1.15	1.16	1.46	0.83
0.88	1.42	1.29	1.22	1.38	0.93	0.96	0.78	1.38	1.14
0.95	1.24	1.07	1.03	0.75	2.05	1.37	0.99	1.60	0.95
1.14	1.39	1.42	1.18	0.93	1.16	1.51	1.31	1.52	1.51
1.42	1.35	0.83	0.99	1.03	1.88	1.66	1.14	1.14	0.92
1.47	1.63	1.05	1.48	0.81	1.66	0.85	1.14	1.41	1.16
1.54	1.86	0.74	1.09	1.81	1.56	1.06	0.92	0.84	0.96
1.03	1.37	0.99	1.06	1.32	1.59	0.91	1.34	0.85	1.71
0.77	1.57	0.98	1.42	0.98	1.36	1.72	1.76	1.56	0.88
1.64	1.12	1.69	1.56	1.23	1.17	0.90	1.12	0.81	1.58
0.95	0.77	0.92	0.93	1.00	1.06	1.41	1.68	1.19	0.95
0.82	0.79	1.58	1.25	0.78	1.35	1.42	0.82	1.35	0.94
1.01	1.49	1.32	0.85	1.37	1.36	1.32	1.05	1.13	1.03
0.82	1.15	0.73	1.74	1.55	1.61	1.64	1.36	1.13	1.30

Table 24: Fire Station #9 Turnout Time Actual

Fire Station #9 Turnout Time Actual (Minutes)									
Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry
0-30	31-60	61-90	91-120	121-150	151-180	181-210	211-240	241-270	271-300
1.00	1.98	0.82	1.82						
1.20	1.53	1.08	1.10						
1.77	0.97	0.92	1.13						
1.80	1.93	0.80	1.67						
1.17	1.08	1.38	1.30						
0.88	1.43	0.77	1.12						
1.52	1.80	1.07	1.67						
1.00	1.13	1.02	0.92						
1.47	1.53	1.20	1.02						
1.05	1.85	0.87	1.40						
1.48	1.75	1.55	0.90						
1.18	0.97	0.98	1.25						
1.30	0.80	1.07	0.78						
0.82	1.03	1.12	1.07						
1.12	1.57	1.85	1.60						
1.57	1.43	1.32	1.23						
1.73	1.02	1.35							
1.30	1.18	1.20							
1.10	0.95	0.78							
1.08	0.90	1.28							
1.83	0.75	1.63							
1.12	1.33	0.93							
1.72	1.53	1.73							
2.00	1.17	1.00							
1.75	1.78	0.83							
1.52	1.13	1.90							
1.17	1.60	1.18							
1.97	1.10	1.83							
0.87	1.32	1.52							
1.05	1.60	1.27							

Table 25: Fire Station #9 Turnout Time Simulated

Fire Station #9 Turnout Time Simulated (Minutes)									
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300
1.11	0.81	1.41	1.53	1.22	1.40	1.49	1.94	1.56	1.19
1.02	0.76	1.08	1.37	1.13	0.94	1.27	1.45	0.97	1.53
1.22	1.31	1.27	1.22	1.88	0.92	0.95	0.88	1.23	1.07
1.47	0.92	1.37	1.34	1.52	1.05	1.40	0.91	1.44	1.16
1.02	1.38	1.17	1.73	1.07	1.24	0.95	1.66	1.04	1.71
1.23	1.51	1.32	1.57	1.41	0.92	1.07	1.15	1.37	1.36
1.19	1.62	0.87	1.22	0.85	1.31	1.76	0.90	0.93	1.40
1.26	1.56	1.50	0.91	1.44	1.47	1.00	1.58	1.50	1.02
0.98	1.40	0.99	1.40	1.42	1.65	1.63	1.02	1.04	1.01
1.39	1.01	1.55	1.59	1.08	0.75	0.93	1.47	0.84	1.65
1.46	1.15	1.01	1.04	0.97	1.58	1.00	0.72	1.08	0.93
1.34	0.94	1.12	1.26	0.97	1.30	1.22	0.85	0.88	1.47
1.44	1.12	1.26	1.06	1.33	1.23	1.42	0.98	1.16	0.99
0.83	1.50	1.68	1.03	1.16	1.56	1.30	1.17	1.28	0.91
1.59	0.98	1.26	0.68	1.87	0.89	1.15	1.80	1.06	1.74
1.51	0.89	1.51	1.43	1.00	1.34	1.09	1.10	1.77	1.14
1.51	1.20	1.34	0.88	0.91	1.53	1.27	1.18	1.47	0.82
0.91	1.46	1.22	1.28	1.40	0.86	1.00	0.81	1.34	1.15
0.95	1.24	1.11	1.06	0.75	2.07	1.38	1.04	1.55	0.94
1.17	1.40	1.43	1.19	0.96	1.12	1.64	1.33	1.42	1.47
1.43	1.36	0.87	1.02	1.10	1.89	1.68	1.02	1.16	0.96
1.48	1.64	1.05	1.49	0.85	1.82	0.86	1.19	1.37	1.17
1.68	1.88	0.74	1.11	1.83	1.52	1.08	0.93	0.84	0.93
1.02	1.40	1.02	1.08	1.29	1.60	0.90	1.35	0.85	1.71
0.77	1.61	0.98	1.44	1.01	1.38	1.47	1.77	1.58	0.89
1.66	1.13	1.60	1.57	1.24	1.21	0.95	1.08	0.81	1.60
0.92	0.81	0.87	0.93	0.99	1.06	1.42	1.70	1.10	0.95
0.83	0.82	1.60	1.21	0.83	1.36	1.41	0.83	1.38	1.01
1.01	1.51	1.33	0.89	1.38	1.37	1.33	1.05	1.14	1.02
0.82	1.19	0.76	1.82	1.57	1.62	1.62	1.45	1.14	1.31

Table 26: Baseline Fire Station Dispatch and Turnout Time Actual

Baseline Fire Station Dispatch and Turnout Time Actual (Minutes)																
Entry 0-30	Entry 31-60	Entry 61-90	Entry 91-120	Entry 121-150	Entry 151-180	Entry 181-210	Entry 211-240	Entry 241-270	Entry 271-300	Entry 301-330	Entry 331-360	Entry 361-390	Entry 391-420	Entry 421-450	Entry 451-480	Entry 481-510
1.40	2.48	1.63	3.07	2.18	3.03	2.25	1.93	2.00	2.83	1.52	2.05	2.63	1.83	3.10	2.93	1.55
2.17	1.97	3.45	1.78	2.00	2.97	3.43	1.55	2.63	1.42	3.08	2.10	2.50	1.35	3.33	1.98	2.82
2.50	1.45	1.42	2.32	1.43	2.98	2.32	2.77	1.27	2.03	1.27	1.82	2.97	2.30	2.42	1.40	
2.40	1.57	1.63	1.48	1.33	3.18	2.18	2.83	1.40	1.67	2.70	2.95	2.12	2.57	3.08	1.72	
2.78	2.43	1.55	1.80	2.62	2.43	1.77	1.52	2.80	2.02	1.38	2.98	1.87	2.78	2.70	2.40	
3.12	3.48	1.92	2.55	2.57	2.42	1.43	1.92	2.62	2.83	2.20	3.03	1.48	3.37	3.20	2.82	
3.20	1.98	2.82	3.35	3.37	3.22	1.45	2.93	1.60	2.40	1.48	3.02	1.30	3.22	2.23	2.97	
3.28	1.37	2.90	1.53	2.93	1.60	1.78	1.62	2.85	3.17	3.07	1.47	3.35	1.42	2.33	3.32	
3.13	2.87	2.45	2.70	2.65	3.40	3.13	3.30	3.25	1.50	2.22	2.63	3.38	2.92	1.58	1.67	
1.78	2.08	2.13	2.43	2.27	2.07	2.37	2.53	1.90	1.90	1.85	1.35	2.97	2.13	2.05	2.67	
3.23	1.68	2.17	2.92	2.07	2.40	2.72	1.88	1.62	3.15	1.33	1.88	1.32	2.67	1.85	3.17	
1.93	2.07	2.75	1.27	2.73	3.30	2.80	1.70	1.70	2.38	2.90	1.87	1.25	1.40	1.98	2.37	
2.50	1.85	1.33	2.10	2.03	2.48	2.85	2.55	1.32	1.72	1.95	3.27	2.03	1.58	3.28	1.65	
2.17	2.95	1.53	2.28	2.38	3.22	2.53	2.60	2.00	3.05	1.28	2.10	3.43	2.88	1.55	2.62	
1.87	1.52	2.27	2.57	1.60	2.38	2.37	2.88	3.20	1.60	2.67	1.93	2.85	1.48	3.15	3.05	
2.32	2.57	2.12	2.52	2.72	2.48	2.45	2.62	2.35	1.28	1.37	2.03	2.22	2.48	2.08	3.48	
2.58	1.97	2.90	3.42	1.72	1.62	3.30	1.47	3.33	1.45	3.22	3.05	2.68	3.47	3.27	1.53	
3.12	3.25	3.17	1.32	1.38	1.75	3.02	2.30	2.80	2.13	1.45	2.88	2.35	1.78	1.50	1.35	
1.88	3.48	2.52	1.50	1.25	2.70	2.27	2.33	2.12	2.28	3.30	2.85	1.73	3.13	1.95	2.72	
3.38	1.85	2.52	1.63	1.42	1.28	2.30	2.07	3.10	2.77	2.65	2.55	1.80	1.95	1.73	2.72	
2.23	2.90	2.02	2.83	1.75	2.23	3.08	2.75	3.38	1.67	1.58	1.77	3.02	2.45	1.70	3.00	
1.98	2.52	3.02	1.35	1.37	3.28	1.87	3.33	1.83	2.75	2.23	2.68	2.18	1.25	1.92	1.77	
3.25	1.27	3.37	2.33	3.25	2.53	2.82	2.30	1.73	1.65	3.27	2.35	1.58	2.10	3.42	2.73	
3.35	2.33	1.37	2.42	2.08	2.20	2.38	1.82	3.45	3.50	2.58	1.53	1.83	2.93	2.25	1.68	
2.15	3.33	2.98	2.25	1.68	2.13	1.50	2.15	2.58	2.87	2.18	1.77	2.47	3.40	1.72	1.82	
1.70	1.90	2.47	2.68	2.92	1.63	2.05	2.53	2.32	1.68	3.13	1.82	1.95	2.05	2.95	2.20	
2.37	3.12	2.27	1.88	2.58	2.77	1.57	2.50	3.47	1.62	1.38	1.65	3.08	1.93	1.33	2.28	
3.18	2.25	2.17	1.28	2.63	1.83	1.32	3.03	2.78	3.15	2.75	1.67	1.80	2.60	3.47	1.90	
3.07	2.78	2.08	2.00	1.47	3.03	2.65	3.23	1.52	2.22	2.45	1.30	2.67	1.75	2.77	2.43	
2.35	1.97	3.00	1.73	2.88	2.55	2.22	1.65	1.92	2.80	2.87	3.40	3.32	1.47	2.65	3.20	

Table 27: Baseline Fire Station Dispatch and Turnout Time Simulated

Baseline Fire Station Dispatch and Turnout Time Simulated (Minutes)									
Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry	Entry
0-30	**31-60**	**61-90**	**91-120**	**121-150**	**151-180**	**181-210**	**211-240**	**241-270**	**271-300**
2.20	2.91	2.45	3.06	2.22	1.88	1.35	1.91	2.52	2.42
2.29	1.91	2.91	2.88	2.29	2.69	2.41	2.62	2.23	2.21
2.86	3.01	2.63	2.46	2.44	1.68	2.10	2.61	2.21	1.72
1.80	2.33	1.77	1.93	2.52	1.76	2.66	2.61	2.82	2.48
2.12	2.29	2.08	2.82	2.23	2.51	2.54	1.78	2.59	2.44
1.76	2.04	2.50	2.63	2.27	2.38	2.59	2.34	2.23	2.86
2.20	2.47	2.39	2.51	2.52	2.18	2.24	2.56	2.01	2.77
2.42	2.27	2.45	1.92	2.38	2.16	2.43	2.40	1.68	1.73
2.20	2.42	2.69	2.28	2.13	2.33	1.81	1.96	2.55	2.26
2.65	2.71	2.39	2.41	2.05	2.14	2.61	1.89	2.16	2.70
2.83	2.24	2.61	1.97	2.10	2.49	2.07	2.53	1.91	2.23
2.31	2.29	1.62	1.68	2.56	2.16	2.24	2.01	2.19	2.68
2.15	1.74	1.85	2.43	2.73	2.24	2.47	2.25	2.47	2.66
2.03	1.88	2.17	2.11	1.96	2.84	2.79	2.03	2.80	2.23
2.14	2.24	2.10	2.54	2.26	2.41	2.00	2.46	2.10	2.65
2.17	1.97	2.51	2.43	2.39	1.63	2.59	2.45	2.63	2.24
2.87	2.91	2.21	2.05	2.27	2.55	2.13	1.70	2.22	1.35
2.12	2.54	1.69	2.99	2.05	2.66	1.95	2.06	2.01	2.16
2.40	1.63	2.40	1.67	2.32	2.43	2.21	2.88	1.79	2.22
2.07	2.58	2.39	2.50	2.13	1.64	2.50	2.07	2.85	2.80
2.35	2.52	2.43	2.01	2.46	2.34	2.68	2.00	2.74	2.28
2.49	2.89	2.73	2.40	2.00	2.05	2.36	2.69	2.74	2.09
2.44	2.28	2.48	2.05	2.19	1.63	1.76	2.00	2.17	2.05
2.38	2.11	2.26	2.46	2.67	2.48	2.55	2.40	2.15	2.24
2.06	2.18	2.39	2.56	2.26	2.20	2.08	2.99	1.94	2.55
2.78	2.21	2.43	2.09	2.47	2.69	2.34	2.20	2.05	2.71
2.07	2.55	2.66	2.37	2.24	1.64	2.26	2.99	2.36	2.78
2.36	2.51	2.80	2.19	2.48	1.69	2.68	2.52	1.79	2.11
1.89	2.29	2.07	2.46	1.98	1.99	2.46	2.25	2.71	2.46
2.42	2.10	2.01	1.95	2.17	2.49	2.24	2.29	2.90	2.72

Table 28: Observed Dispatcher Activity

Obseved Dispatcher Activity (Seconds)	
Dispatcher Completes Emergency Phone	**Dispatcher Relays Information over Intercom**
26	8
29	9
22	8
35	10
32	10
23	8
45	12
20	7
45	12
42	11
21	8
19	7
28	9
43	11
41	11
18	7
36	10
27	9
20	7
28	9
46	12
25	8
15	6
24	8
47	12

Table 29: Observed Pre-Movement Activity

Observed Time to Conduct Pre-Movement Activity (Seconds)							
Dorm	Kitchen	Restroom/ Shower	Recreation	Gym	Training Room	Bay	Admin
23	15	10	3	5	5	7	5
12	12	12	7	14	6	14	5
11	18	15	5	10	4	15	5
16	15	22	12	19	5	9	3
15	5	15	13	25	3	7	6
23	9	6	5	15	5	6	6
10	8	5	5	9	7	7	7
20	16	15	7	17		5	5
15	15	7	15	10		11	6
11	17	18	4			5	3
16	19	33	14			14	5
25	20	45	11			7	7
14		9					
8		18					
14							
15							
5							
35							

Table 30: Observed Travel Times

Observed Travel Times To Station Bay (Seconds)							
Dorm	Kitchen	Restroom/ Shower	Recreation	Gym	Training Room	Bay	Admin
26	39	27	31	29	23	1	33
29	41	31	29	39	27	2	36
22	27	34	41	25	26	2	27
30	30	25	34	23	20	2	35
29	31	33	36	33	23	2	37
23	30	27	45	25	21	3	37
23	37	23	37	30	24	1	29
24	34	31	45	33	23	1	32
23	26	32	31	36	26	2	31
30	29	30	27	33	25	2	28

Table 31: Observed Time to Don Equipment

Observed Time to Don Equipment (Seconds)		
Medical	**Structural**	**Airfield**
25	41	23
24	26	47
16	24	39
12	44	27
12	36	35
15	38	30
15	53	47
10	22	43
15	45	53
21	22	36

Table 32: Observed Pre-Vehicle Movement

Observed Time to Conduct Pre-Vehicle Movement Activity (Seconds)		
Driver	**Navigator**	**Passenger**
25	14	17
10	11	7
20	10	5
16	10	14
24	15	15
11	10	7
11	9	19
20	5	20
12	13	15
20	11	15

Table 33: Observed Garage Opening Time

Observed Time to Open Garage (Seconds)	
Garage Door Opening	Dispatcher opens Garage
18	4
18	4
19	4
20	4
18	5
22	3
20	4
20	4
21	5
20	5

References

Abrahamsson, M., Hassel, H., & Tehler, H. (2010). Towards a System-Oriented Framework for Analysing and Evaluating Emergency Response. *Journal of Contingencies and Crisis Management*, *18*(1), 14–25.

Aleisa, E. E., & Lin, L. (2005). For effective facilities planning: layout optimization then simulation, or vice versa? (p. 5–pp). Presented at the Proceedings of the Winter Simulation Conference, 2005., IEEE.

Altiok, T., & Melamed, B. (2001). Simulation Modeling and Analysis with Arena. Cyber Research. *Inc. and Enterprise Technology Solutions, Inc*.

Ashforth, B. E., & Humphrey, R. H. (1995). Emotion in the workplace: A reappraisal. *Human Relations*, *48*(2), 97–125.

Badri, M. A., Mortagy, A. K., & Alsayed, C. A. (1998). A multi-objective model for locating fire stations. *European Journal of Operational Research*, *110*(2), 243–260.

Ball, M. O., & Lin, F. L. (1993). A reliability model applied to emergency service vehicle location. *Operations Research*, *41*(1), 18–36.

Banks, J., CARSON II, J. S., & Barry, L. (2005). *Discrete-event system simulationfourth edition*. Pearson.

Bertolini, M., Bevilacqua, M., & Massini, R. (2006). FMECA approach to product traceability in the food industry. *Food Control*, *17*(2), 137–145.

Billinton, R., & Wangdee, W. (2006). Predicting bulk electricity system reliability performance indices using sequential Monte Carlo simulation. *IEEE Transactions on Power Delivery*, *21*(2), 909–917.

Birren, F. (2016). *Color psychology and color therapy; a factual study of the influence of color on human life*. Pickle Partners Publishing.

Bohannon, R. W. (1997). Comfortable and maximum walking speed of adults aged 20—79 years: reference values and determinants. *Age and Ageing*, *26*(1), 15–19.

Burgess, A., Morgan, I., & Vollmann, T. (1993). Cellular manufacturing: its impact on the total factory. *The International Journal of Production Research*, *31*(9), 2059–2077.

Canter, D., Breaux, J., & Sime, J. (1980). Domestic, multiple occupancy and hospital fires. *Fires and Human Behaviour*, 117–136.

Center for Public Safety Excellence. (2016). Retrieved August 1, 2016, from http://www.cpse.org/

Clarke, L. (2006). *Worst cases: Terror and catastrophe in the popular imagination*. University of Chicago Press.

Colquitt, J., Lepine, J. A., & Wesson, M. J. (2011). *Organizational behavior: Improving performance and commitment in the workplace*. McGraw-Hill Irwin.

Commission on fire accreditation international accreditation model information technology specifications. (2016, October). Retrieved from http://www.cpse.org/LinkClick.aspx?fileticket=KTFIlutz_fk%3d&tabid=73

Dai, F. C., Lee, C. F., & Ngai, Y. Y. (2002). Landslide risk assessment and management: an overview. *Engineering Geology*, *64*(1), 65–87. https://doi.org/10.1016/S0013-7952(01)00093-X

Ditlevsen, O., & Madsen, H. O. (1996). *Structural reliability methods* (Vol. 178). Wiley New York.

Drira, A., Pierreval, H., & Hajri-Gabouj, S. (2007). Facility layout problems: A survey. *Annual Reviews in Control*, *31*(2), 255–267.

Duguay, C., & Chetouane, F. (2007). Modeling and improving emergency department systems using discrete event simulation. *Simulation*, *83*(4), 311–320.

Elliot, A. J., & Maier, M. A. (2014). Color psychology: Effects of perceiving color on psychological functioning in humans. *Annual Review of Psychology*, *65*, 95–120.

Ericson, C. A., & Ll, C. (1999). Fault tree analysis (pp. 1–9). Presented at the System Safety Conference, Orlando, Florida.

Faber, M. H., & Stewart, M. G. (2003). Risk assessment for civil engineering facilities: critical overview and discussion. *Reliability Engineering & System Safety*, *80*(2), 173–184. https://doi.org/10.1016/S0951-8320(03)00027-9

FEMA Chapter 9 - Preparedness for Emergency Response. (2016). Retrieved January 1, 2017, from https://training.fema.gov/hiedu/docs/fem/chapter%209%20-%20preparedness%20for%20emergency%20response.doc

Fishman, G. (2013). *Discrete-event simulation: modeling, programming, and analysis*. Springer Science & Business Media.

Fujimoto, R. M. (1990). Parallel discrete event simulation. *Communications of the ACM*, *33*(10), 30–53.

Furian, N., O'sullivan, M., Walker, C., Vössner, S., & Neubacher, D. (2015). A conceptual modeling framework for discrete event simulation using hierarchical control structures. *Simulation Modelling Practice and Theory*, *56*, 82–96.

Gan, H.-S., Richter, K.-F., Shi, M., & Winter, S. (2016). Integration of simulation and optimization for evacuation planning. *Simulation Modelling Practice and Theory*, *67*, 59–73.

George, J. M., Jones, G. R., & Sharbrough, W. C. (1996). *Understanding and managing organizational behavior*. Addison-Wesley Reading, MA.

Glenn, A., & Vergara, H. A. (2016). Facility planning for large equine facilities in urban and rural settings. *Computers and Electronics in Agriculture*, *130*, 151–157.

Greasley, A. (2008). Using simulation for facility design: A case study. *Simulation Modelling Practice and Theory*, *16*(6), 670–677.

Greszler, B., Gallucci, D., & Sundheim, M. (2015, June). *An Analysis of Fire and Emergency Services Aggregate Response Times*. Unpublished Manuscript, Air Force Institute of Technology.

Grund, C., & Westergård-Nielsen, N. (2008). Age structure of the workforce and firm performance. *International Journal of Manpower*, *29*(5), 410–422.

Günal, M. M., & Pidd, M. (2010). Discrete event simulation for performance modelling in health care: a review of the literature. *Journal of Simulation*, *4*(1), 42–51.

Gwynne, S., Galea, E. R., Owen, M., Lawrence, P. J., & Filippidis, L. (1999). A review of the methodologies used in the computer simulation of evacuation from the built environment. *Building and Environment*, *34*(6), 741–749. https://doi.org/10.1016/S0360-1323(98)00057-2

Hackman, J. R., & Oldham, G. R. (1976). Motivation through the design of work: Test of a theory. *Organizational Behavior and Human Performance*, *16*(2), 250–279.

Haden, D. (2016). Realistic response times. Retrieved November 8, 2016, from http://www.firefightingincanada.com/response/realistic-response-times-10985

Hayes, B. E., Perander, J., Smecko, T., & Trask, J. (1998). Measuring perceptions of workplace safety: Development and validation of the work safety scale. *Journal of Safety Research*, *29*(3), 145–161.

Henstra, D. (2010). Evaluating local government emergency management programs: what framework should public managers adopt? *Public Administration Review*, *70*(2), 236–246.

Himann, J. E., Cunningham, D. A., Rechnitzer, P. A., & Paterson, D. H. (1988). Age-related changes in speed of walking. *Medicine and Science in Sports and Exercise*, *20*(2), 161–166.

Hopfe, C. J., & Hensen, J. L. M. (2011). Uncertainty analysis in building performance simulation for design support. *Energy and Buildings*, *43*(10), 2798–2805. https://doi.org/10.1016/j.enbuild.2011.06.034

Iannone, R., Miranda, S., Prisco, L., Riemma, S., & Sarno, D. (2016). Proposal for a flexible discrete event simulation model for assessing the daily operation decisions in a Ro–Ro terminal. *Simulation Modelling Practice and Theory*, *61*, 28–46.

Jackson, B. A., Faith, K. S., & Willis, H. H. (2010). *Evaluating the reliability of emergency response systems for large-scale incident operations*. DTIC Document.

Jackson, B. A., Sullivan Faith, K., & Willis, H. H. (2011). Are We Prepared? Using Reliability Analysis to Evaluate Emergency Response Systems. *Journal of Contingencies and Crisis Management*, *19*(3), 147–157. https://doi.org/10.1111/j.1468-5973.2011.00641.x

Jacobson, S. H., Hall, S. N., & Swisher, J. R. (2013). Discrete-Event Simulation of Health care Systems. In R. Hall (Ed.), *Patient Flow: Reducing Delay in Healthcare Delivery* (pp. 273–309). Boston, MA: Springer US. Retrieved from http://dx.doi.org/10.1007/978-1-4614-9512-3_12

Jun, J. B., Jacobson, S. H., & Swisher, J. R. (1999). Application of discrete-event simulation in health care clinics: A survey. *Journal of the Operational Research Society*, *50*(2), 109–123. https://doi.org/10.1057/palgrave.jors.2600669

Kam, C., & Fischer, M. (2004). Capitalizing on early project decision-making opportunities to improve facility design, construction, and life-cycle performance—POP, PM4D, and decision dashboard approaches. *Automation in Construction*, *13*(1), 53–65.

Kelton, W. D. (2002). *Simulation with ARENA*. McGraw-Hill.

Komashie, A., & Mousavi, A. (2005). Modeling emergency departments using discrete event simulation techniques (pp. 2681–2685). Presented at the Proceedings of the 37th conference on Winter simulation, Winter Simulation Conference.

Kusiak, A., & Heragu, S. S. (1987). The facility layout problem. *European Journal of Operational Research*, *29*(3), 229–251.

Liggett, R. S. (2000). Automated facilities layout: past, present and future. *Automation in Construction*, *9*(2), 197–215.

Linstone, H. A., & Turoff, M. (1975). *The Delphi method: Techniques and applications* (Vol. 29). Addison-Wesley Reading, MA.

Malone, D. M. (1983). *Small unit leadership: A commonsense approach*. Random House Digital, Inc.

Mathews, K. E., & Canon, L. K. (1975). Environmental noise level as a determinant of helping behavior. *Journal of Personality and Social Psychology*, *32*(4), 571.

Mattsson, B., & Juås, B. (1997). The importance of the time factor in fire and rescue service operations in Sweden. *Accident Analysis & Prevention*, *29*(6), 849–857. https://doi.org/10.1016/S0001-4575(97)00054-7

Melchers, R. E. (2001). On the ALARP approach to risk management. *Reliability Engineering & System Safety*, *71*(2), 201–208.

Meller, R. D., & Gau, K.-Y. (1996). The facility layout problem: recent and emerging trends and perspectives. *Journal of Manufacturing Systems*, *15*(5), 351–366.

Mesagna, E., & Raroni, J. (1991). Fire Department Facilities and Fire Training Facilities. *The Fire Protection Handbook, 17th Edition,(Boston: NFPA 1991)*.

Miner, J. B. (2003). The rated importance, scientific validity, and practical usefulness of organizational behavior theories: A quantitative review. *Academy of Management Learning & Education*, *2*(3), 250–268.

Mitroff, I. I., & Alpaslan, M. C. (2003). *Preparing for evil*. Harvard Business School Pub.

Müller, S. (2015). Spaces of Rites and Locations of Risk: The Great Pilgrimage to Mecca. In S. D. Brunn (Ed.), *The Changing World Religion Map: Sacred Places,* *Identities, Practices and Politics* (pp. 841–853). Dordrecht: Springer Netherlands. Retrieved from http://dx.doi.org/10.1007/978-94-017-9376-6_42

National 911 Program. (2013). Retrieved from http://www.911.gov/pdf/Current911DataCollection-072613.pdf

National Fire and Protection Agency. (2016). Retrieved November 6, 2016, from http://www.nfpa.org/

Navara, K. J., & Nelson, R. J. (2007). The dark side of light at night: physiological, epidemiological, and ecological consequences. *Journal of Pineal Research*, *43*(3), 215–224.

Needham, F. A., Anundson, R. L., Smith, G. R., & Goschen, K. F. (2007). Responder route and site-specific critical data system.

Pell, J. P., Sirel, J. M., Marsden, A. K., Ford, I., & Cobbe, S. M. (2001). Effect of reducing ambulance response times on deaths from out of hospital cardiac arrest: cohort study. *BMJ : British Medical Journal*, *322*(7299), 1385–1388.

Plane, D. R., & Hendrick, T. E. (1977). Mathematical programming and the location of fire companies for the Denver fire department. *Operations Research*, *25*(4), 563–578.

Proulx, G. (1994). The Time Delay to Start Evacuating upon Hearing a Fire Alarm. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *38*(14), 811–815. https://doi.org/10.1177/154193129403801403

Proulx, G. (2001). Occupant behaviour and evacuation (pp. 219–232). Presented at the Proceedings of the 9th International Fire Protection Symposium.

Quińones, M. A., Ford, J. K., & Teachout, M. S. (1995). The relationship between work experience and job performance: A conceptual and meta-analytic review. *Personnel Psychology*, *48*(4), 887–910.

Raman, D., Nagalingam, S. V., & Lin, G. C. (2009). Towards measuring the effectiveness of a facilities layout. *Robotics and Computer-Integrated Manufacturing*, *25*(1), 191–203.

Ramirez-Valdivia, M., Christian, P., Govande, V., & Zimmers, E. (2000). Design and implementation of a cellular manufacturing process: A simulation modeling approach. *International Journal of Industrial Engineering-Theory Applications and Practice*, *7*(4), 281–285.

Rice, D. P., & Cooper, B. S. (1967). The economic value of human life. *American Journal of Public Health and the Nations Health*, *57*(11), 1954–1966.

Ripley, A. (2009). *The unthinkable: Who survives when disaster strikes-and why*. Harmony Books.

Robert E. Melchers. (1999). *Structural reliability analysis and prediction*. John Wiley & Son Ltd.

Sackett, P. R. (2002). The structure of counterproductive work behaviors: Dimensionality and relationships with facets of job performance. *International Journal of Selection and Assessment*, *10*(1-2), 5–11.

Sarmady, S., Haron, F., & Talib, A. Z. (2007). Agent-Based Simulation Of Crowd At The Tawaf Area.

Schreuder, J. (1981). Application of a location model to fire stations in Rotterdam. *European Journal of Operational Research*, *6*(2), 212–219.

Scott, C., & Myers, K. K. (2005). The socialization of emotion: Learning emotion management at the fire station. *Journal of Applied Communication Research*, *33*(1), 67–92.

Sime, J. D. (1985). Movement toward the familiar person and place affiliation in a fire entrapment setting. *Environment and Behavior*, *17*(6), 697–724.

Stauber, J. (2003). *Is the NFPA 1710 standard one-minute turnout time goal for career fire departments reasonable and achievable?* (p. 66). Green Bay Fire Department Green Bay, Wisconsin: An applied research project submitted to the National Fire Academy as part of the Executive Fire Officer Program. Retrieved from https://www.usfa.fema.gov/pdf/efop/efo34405.pdf

Stevens, R. G. (2009). Light-at-night, circadian disruption and breast cancer: assessment of existing evidence. *International Journal of Epidemiology*, *38*(4), 963–970.

Tzeng, G., & Chen, Y. (1999). The optimal location of airport fire stations: a fuzzy multi-objective programming and revised genetic algorithm approach. *Transportation Planning and Technology*, *23*(1), 37–55.

Unified Facilities Criteria 4-730-10 Fire Stations. (2006, June 15). Department of Defence. Retrieved from http://www.wbdg.org/ccb/DOD/UFC/ufc_4_730_10.pdf

Weninger, S. (2004). *Emergency Response Turnout Times*. National Fire Academy.

Wu, C.-H., & Chen, L.-C. (2012). 3D spatial information for fire-fighting search and rescue route analysis within buildings. *Fire Safety Journal*, *48*, 21–29.

Yaman, R., & Balibek, E. (1999). Decision making for facility layout problem solutions. *Computers & Industrial Engineering*, *37*(1), 319–322.

Yang, L., Jones, B. F., & Yang, S.-H. (2007). A fuzzy multi-objective programming for optimization of fire station locations through genetic algorithms. *European Journal of Operational Research*, *181*(2), 903–915.

Yanmaz, A. M. (2000). Overtopping risk assessment in river diversion facility design. *Canadian Journal of Civil Engineering*, *27*(2), 319–326. https://doi.org/10.1139/l99-074

Zheng, X., Zhong, T., & Liu, M. (2009). Modeling crowd evacuation of a building based on seven methodological approaches. *Building and Environment*, *44*(3), 437–445.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
23-03-2017	Master's Thesis	Oct 2015-March 2017

4. TITLE AND SUBTITLE
Improving Fire Station Turnout Time Through Discrete-Event Simulation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Vaira, Keegan D, Capt

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/ENV)
2950 Hobson Way, Building 640
WPAFB OH 45433-8865

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT-ENV-MS-17-M-233

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Wright Patterson AFB Fire Emergency Services
Skeel Ave #206, Wright-Patterson AFB, OH 45433
POC: Mr. Larry Osterhage
Email: larry.osterhage@us.af.mil
Phone: 937-904-3167

10. SPONSOR/MONITOR'S ACRONYM(S)
WPAFB FS#1

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The fire station is a critical aspect of the emergency response system, yet the role fire station design plays during an emergency response is rarely studied. This research applies the facility layout problem through the use of discrete-event simulation to both improve existing fire stations and to find optimal designs for new fire station construction. The discrete-event simulation model describes the effectiveness of a fire station by measuring and predicting turnout time. This research found a potential 28.85% reduction in turnout time for a case study fire station through facility layout improvement methods and provides a design tool that predicts fire station turnout time for facility layout construction methods. Applying this research could positively impact the nation's emergency response system and reduce the risk of losing life, limb, and property to communities served by improved fire stations.

15. SUBJECT TERMS
Discrete-Event Simulation, Emergency Management, Process Improvement, Facility Layout Problem

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Maj Christina F. Rusnock AFIT/ENV
U	U	U	UU	176	**19b. TELEPHONE NUMBER** *(Include area code)* (937) 255-6565, x 4611 christina.rusnock@afit.edu

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18